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April 22, 1992
WCC Project 90C7040

Mr. Alan Hancock
U.S. Environmental Protection Agency Region VII
726 Minnesota Avenue
Kansas City, Kansas 66101

Re: Abbott Laboratories, Wichita, Kansas
RCRA Facility Investigation Report

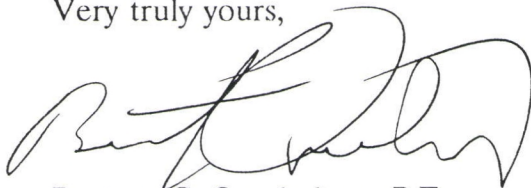
Dear Mr. Hancock:

On behalf of Abbott Laboratories, please find enclosed the Final RCRA Facility Investigation Report for the Abbott Laboratories Wichita Facility, prepared by Woodward-Clyde Consultants in accordance with the Administrative Order on Consent, effective date July 23, 1991. Four copies of the report and appendices are included.

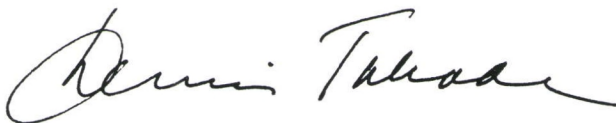
In order to facilitate your review, we have provided, in addition to the revised reports, a redlined version of the text of the report and an attachment which provides a point by point summary of EPA's comments and Abbott's responses.

Please call if you have any questions or comments.

Very truly yours,



Bretton C. Overholtzer, P.E.
Project Engineer



Dennis Y. Takade, Ph.D.
Vice President & Senior Associate

cc: Bob Malson, Abbott Laboratories
John C. Irwin, KDHE (2 copies)

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■ ■ ■ ■ ■ ■ ■ ■ ■ ■ RCRA FACILITY
INVESTIGATION
ABBOTT
LABORATORIES
WICHITA, KANSAS

Prepared for
U.S. Environmental
Protection Agency
Kansas City, Kansas 66101
and
Kansas Department of
Health and Environment
Forbes Field
Topeka, Kansas 66620-0001
April 1992

Woodward-Clyde 

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P.O. Box 3777
Overland Park, Kansas 66203-0777

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Project Number 90C7040

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EXECUTIVE SUMMARY

Abbott Laboratories (Abbott) is performing a RCRA Facility Investigation (RFI) of its presently owned property (Facility) at its former manufacturing site (Site) in Wichita, Kansas. The RFI is conducted pursuant to an Administrative Order on Consent between Abbott and the United States Environmental Protection Agency, which became effective on July 23, 1990.

The Facility, located about five miles to the southwest of Wichita, Kansas, is comprised of approximately 20 acres, and is surrounded by industrial, residential, and commercial lands (see Drawing 1). Abbott sold the operational portion of the Site to Air Products and Chemicals, Inc. on July 31, 1985, but retained ownership of four Solid Waste Management Units (SWMUs) and the real property on which the SWMUs are located. The SWMUs retained by Abbott are:

- The evaporation pond;
- The evaporation lagoon;
- The hazardous waste drum storage pad; and
- The underground injection control (UIC) deep injection well.

All of the SWMUs have been closed under Kansas Department of Health and Environment direction except for the UIC well, which is still in operation.

Abbott commenced operations at this location in 1960. The original Site was constructed to produce cyclohexylamine, used in the production of an artificial sweetener. The Site was later diversified to produce amine-based intermediate products which are used in the production of textiles, rubber, plastics, adhesives, and pharmaceuticals.

Groundwater contamination was discovered in 1977 and first studied in detail in 1979. Since 1979, Abbott has operated a voluntary extraction well system to remediate the groundwater contamination beneath the Facility.

The goals of the RFI are to determine the nature and extent of contamination at the Facility through consideration of:

- The environmental setting;
- The source characterization;
- The contaminant characterization
- An identification of the actual and potential receptors.

The RFI report presents data to meet the above objectives and to support the development and evaluation of corrective measures alternatives. Much of the data were collected during field activities which were performed in accordance with the USEPA-approved RFI Work Plan (WCC, 1991b). The RFI field activities included:

- Constructing additional monitoring well clusters to collect additional water quality and geologic data;
- Drilling geotechnical borings to investigate the unconsolidated sediments above the water table in the vicinity of the potential source areas;
- Collecting shallow soil samples, leachate samples, and deep soil samples to characterize the potential source areas;
- Drilling and packer testing a 50-foot core into the Wellington Shale formation beneath the Facility; and
- Conducting groundwater and surface water surveys to identify current and potential future impacts in the area.

Analysis of the data collected from the RFI field activities show that the surface soil types at the Facility are silty clay loam and blanket silt loam. In the subsurface, the unconsolidated sediments at the Facility are comprised of layers of sand and clay

stratification. Regional groundwater flow is generally southeast, but local pumpage for irrigation, plant water supply, and groundwater remediation disrupt the overall regional pattern.

The primary medium of concern is groundwater. There is no evidence of the presence of Abbott chemicals of concern in surface water, surface soil, or sediment around the Facility. The results of the RFI indicate that the probable source for the chemicals of concern in the groundwater is the former evaporation pond.

The data collected during the RFI indicate that the groundwater contaminant plume is localized within the immediate vicinity of the Facility, and that the groundwater contamination is being captured by the existing extraction system. The historical and RFI-derived groundwater analytical data suggest that the extraction program has been effective in reducing the levels of many contaminants of concern at the Facility.

The data collected for this RFI report are of sufficient quantity and quality to meet the intent of the Administrative Order on Consent. No additional data are required at this time to complete the Risk Assessment or the Corrective Measures Study.

Corrective measures alternatives for groundwater remediation were originally outlined in the Pre-Investigation Evaluation Report (WCC, 1990c). The Pre-Investigation Evaluation Report concluded that the long-term corrective action at the Facility is expected to be continuation of the currently operating extraction and injection well system. Evaluation of the corrective measures and treatment technologies will be further developed in the Corrective Measures Study.

INTRODUCTION AND BACKGROUND

Abbott Laboratories (Abbott) is performing a RCRA Facility Investigation (RFI) of its presently owned property (Facility) at its former manufacturing site (Site) in Wichita, Kansas (see Drawing 1). The RFI is conducted pursuant to an Administrative Order on Consent (AOC) between Abbott and the United States Environmental Protection Agency (USEPA), which became effective on July 23, 1990 (USEPA, 1990). The purpose of the RFI is to characterize the potential pathways of contaminant migration, evaluate the sources of contamination, define the degree and extent of groundwater contamination, assess potential human and environmental impacts, and support development of corrective measures, as appropriate. An integral function of the RFI characterization was to differentiate Abbott contaminant sources and constituents from off-site sources.

The RFI program is based upon a large amount of prior work at the Facility which was performed with the review and approval of USEPA and the Kansas Department of Health and Environment (KDHE). Other related activities have also been conducted concurrently with the RFI. These activities are summarized in the following documents:

- Interim Measures Work Plan - September 6, 1990
Presents operating plans for ongoing Interim Measures at the Facility (WCC, 1990a).
- Current Conditions Report - October 11, 1990
Presents a summary of history and current conditions at the Facility (WCC, 1990b).
- Pre-Investigation Evaluation Report - October 11, 1990
Summarizes potential corrective measures and field data needs for evaluation of alternatives (WCC, 1990c).

- RFI Work Plan - March 1, 1991
Describes the data needs for the overall RFI program and identifies the work activities to provide for remedial data (WCC 1991b). Two companion documents to the RFI Work Plan are the Field Sampling Plan (WCC, 1991c) and the Quality Assurance Project Plan (WCC, 1991d).
- Input Data Report for the Numerical Groundwater Flow Model - February, 1991.
Summarizes the information required to operate the numerical flow model and presents the rationale for model parameters (WCC, 1991a).
- Pumping Test Data Analysis Report - March 20, 1991
Summarizes the pumping test activities and presents the result of the analysis of the pumping test data (WCC, 1991e).
- Calibration Report for the Numerical Groundwater Flow Model - July 1991.
Presents additional input data for the numerical groundwater flow model and summarizes the results of model calibration activities (WCC, 1991f).
- Technical Memorandum on the Development of Reference Doses for Groundwater Constituents - September, 1991
Presents the rationale and methodology for the development of groundwater reference doses to be used in the Risk Assessment (WCC, 1991g).

Each of these documents has been submitted to USEPA and KDHE under separate cover.

1.1 PURPOSE OF REPORT

The goal of the RFI conducted at the Facility is to determine the nature and extent of any releases of hazardous waste or hazardous constituents. The following RFI report presents the results of this investigation. The RFI is the second step in a three-step process of:

1. Interim measures to reduce potential migration of contamination;
2. RFI to determine nature and extent of contamination; and
3. Corrective Measures Study (CMS) to identify and evaluate alternatives to prevent or mitigate any migration or releases of contamination.

In order to meet the goals of the determination of nature and extent of contamination, it is necessary to address the following considerations:

- Characterize the Facility (environmental setting);
- Define the source of contamination (source characterization);
- Define the concentration and extent of contamination (contaminant characterization); and
- Identify actual and potential receptors.

This RFI report presents data to meet the above specific objectives and to support the development and evaluation of corrective measures alternatives. Much of the data were collected during field activities which were performed in accordance with the USEPA approved RFI Work Plan (WCC, 1991b). A baseline risk assessment is also included as a preliminary step toward the development of health-based cleanup goals that will be required in the future corrective measures study. The baseline risk assessment also addresses environmental exposure pathways and potential environmental receptors.

A discussion of existing environmental standards that are applicable to the Facility is included to aid in assessing the nature of the contamination.

1.1.1 Organization of the RFI Report

This RFI report is organized to summarize the data currently available for the Facility and to provide a format which allows for rapid correlation with the investigation requirements as presented in the AOC. As a result, some of the information is presented more than once. The report sections are organized as follows:

- Section 1.0 of this report provides an introduction to the Facility and its history, including facility operations, waste disposal facility closures, and previous studies which concern the Facility.
- Section 2.0 summarizes the investigations which were performed at the Facility as part of the RFI. These investigations included field activities and other studies, and were performed in accordance with the USEPA-approved RFI Work Plan (WCC, 1991b). The methodology and rationale for the field activities are presented in this section.
- The physical characteristics of the Facility are presented in Section 3.0. The discussion includes information on the meteorology, geology, hydrology and land use of the area surrounding the Facility.
- Section 4.0 focuses on the physical results of the field activities, which include descriptions of the environmental setting (such as the local hydrogeologic conditions) and source characterization (such as unit and disposal area characteristics and waste characteristics).
- The analytical results of the field activities are summarized in Section 5.0. The analytical summaries include the results of the quarterly groundwater sampling and the results of the waste source characterization sampling.
- The purpose of Section 6.0 is to present information available from the literature on the environmental fate and potential mechanisms for transport to the various constituents detected in the ground- water at the Facility. Data on the chemical and physical properties, persistence, and potential for migration are presented in this section.
- A brief discussion of the analytical quality of the data collected during the RFI is presented in Section 7.0.
- Section 8.0 presents a discussion of the relevant and applicable environmental standards or regulations that pertain to the Facility.
- Section 9.0 summarizes the results of the Baseline Risk Assessment.

- The nature and extent of ground water contamination at the Facility is discussed in Section 10.0. This section presents a summary of the on-going voluntary extraction well program, which has been continuously remediating the ground water beneath the Facility since 1979. Discussions of the ground water flow beneath the Facility, including velocity and direction, and plume extent are included in this section.
- Section 11.0 summarizes the results of the RFI and presents recommendations for future activities, principally the Corrective Measures Study.
- Section 12.0 contains references which are cited in the body of the RFI report.

1.2 FACILITY DESCRIPTION

The address of the Facility is 6765 South Ridge Road, about five miles to the southwest of Wichita, Kansas. The Facility is located in Sedgwick County, in the south half of the northeast quarter of Section 33, Range 1 West, Township 28 South, at a north latitude of 37°34'20" and a west longitude of 97°25'30" (see Drawing 1). The Facility, which comprises approximately 20 acres, is surrounded by industrial, residential, and agricultural lands. Drawing 2 shows legal owners of adjacent property. A series of photographs are included in the back of this Report that show the Facility and the surrounding area.

Since 1979, Abbott has operated a voluntary extraction well program to remediate the groundwater beneath the Facility. The extraction well system consists of two extraction wells, EW-10 and EW-17, which pump continuously at rates of approximately 36 gallons per minute (gpm) and 93 gpm, respectively. Well EW-10 was formerly used by Abbott for plant production and potable water. Well EW-17 (and its subsequent replacement well) was constructed exclusively for the remediation effort. Groundwater is extracted from EW-10 and EW-17, piped to a 5,000-gallon holding/equalization tank, and then flows by gravity to the UIC injection well. An in-line granular activated carbon treatment system is located on the piping between EW-10 and the holding tank. The treatment system is required to reduce the concentrations of chlorinated hydrocarbons to acceptable levels prior to disposal down the injection well.

1.3 FACILITY BACKGROUND AND HISTORY

Abbott Laboratories commenced operations at this location in 1960. The original Site was constructed to produce cyclohexylamine ($C_6H_{11}NH_2$) used in the production of an artificial sweetener. The Site was later diversified to produce amine-based intermediate products which are used in the production of textiles, rubber, plastics, adhesives, and pharmaceuticals. Table 1 presents the names and selected properties of the chemicals used at the Site. Several Site expansions occurred, primarily in 1973, 1976, 1979, and 1980 (KDHE, 1988). The Site was comprised of an operational portion and waste handling, storage and disposal areas.

Abbott sold the operational portion of the Site to Air Products and Chemicals, Inc. on July 31, 1985, but retained ownership of the four Solid Waste Management Units (SWMUs) and the real property on which the SWMUs are located.

The SWMUs retained by Abbott are:

- The Evaporation Pond;
- The Evaporation Lagoon;
- The Hazardous Waste Drum Storage Pad; and
- The Underground Injection Control (UIC) Deep Injection Well.

All of the above SWMUs have been closed under the Kansas Department of Health and Environment (KDHE) direction except the UIC well, which is still in operation. Each SWMU will be described in detail in the following section.

1.3.1 Solid Waste Management Units

This section presents a summary of the historic and characteristic data pertaining to the SWMUs which have been identified at the Facility. The SWMUs, one active and three inactive, are indicated on Drawing 3, presented in the photographs in the back of this report, and identified and summarized in this section.

1.3.1.1 Solid Waste Evaporation Pond

The former solid waste evaporation pond was located between the drum storage pad and the UIC well. The pond was constructed in 1960 and closure was completed in 1981. The pond was approximately one acre in area, approximately 1.3 million-gallon-capacity, and was constructed with a compacted clay liner. The evaporation pond was constructed to treat process wastewaters by evaporation and was designed for zero discharge. Waste constituents were identified in the pond at closure from samples of the remaining sludge, and consisted of amines, cyclohexylamine, dicyclohexylamine, N,N-dimethylcyclohexylamine, acrylonitrile, benzene, and toluene (KDHE, 1988). Maximum influent flow rate to the evaporation pond was approximately 10 to 15 gpm initially, and peaked at an average flow of 28 gpm after several plant expansions. The evaporation pond was closed in 1981 after construction of the evaporation lagoon. The closure was accomplished by pushing in the berm and capping with an 18-inch clay cap and a 6-inch soil cover. An asphalt cap was added in 1983 to further reduce infiltration.

1.3.1.2 Drum Storage Pad

The drum storage pad was constructed in 1974 and closure of the pad was completed in 1986. The location of the pad is indicated on Drawing 3.

The pad was a 70-foot by 65-foot concrete pad surrounded by an earthen ditch and dike with a capacity of 2,184, 55-gallon drums. The pad was used to store waste until the wastes could be recycled or disposed at a permitted disposal facility. All drainage within the pad area led to a sump and pump collection system. Wastes stored at the pad included spent toluene, methanol solvent wastes, and ignitable corrosive wastes (USEPA, 1990).

1.3.1.3 Solid Waste Evaporation Lagoon

The solid waste evaporation lagoon is located in the western portion of the Facility, as shown on Drawing 3, and had a capacity of approximately 8.25 million gallons. The lagoon was constructed in 1980 and operated until 1986 to dispose of process wastewater by evaporation with zero discharge. The lagoon was constructed with a clay

liner and included a leachate collection system which drained to a sump on the north side of the lagoon. Leachate produced from the leachate collection system originally was pumped from the sump back to the lagoon. After the UIC well was constructed, and at the time of the lagoon's closure in 1987, the collected leachate was disposed down the UIC well. Waste constituents identified in the lagoon at the time of closure consisted of amines, cyclohexylamine, dicyclohexylamine, acrylonitrile, benzene, and toluene (KDHE, 1988). The sides of the lagoon were pushed in at closure and the lagoon was capped by a 2-foot thick clay seal followed by a soil cover. The leachate collection system, sump, and sump pumps were left in place to collect leachate resulting from infiltration and percolation. Leachate collected from the lagoon collection system continues to be disposed of by injection in the UIC well.

1.3.1.4 Solid Waste UIC Deep Injection Well

The UIC well is located south of the evaporation pond in the southeast corner of the Facility, as shown on Drawing 3 and is the only active SWMU at the Facility. The well was constructed in 1981 to dispose of production wastewater, leachate from the evaporation lagoon, and contaminated groundwater from the ongoing remediation at the Facility. Details of the UIC well installation are shown in Drawing 5. The well is composed of a 7.75-inch diameter outer casing cemented from depth to the surface and a 4.5-inch diameter inner injection string. The annular space between the casing and injection string has historically contained diesel fuel at a surface annular pressure of approximately 150 to 160 pounds per square inch gage (psig). Annular pressure monitoring serves as a leak detection method and is required by the UIC well permit granted by KDHE (state primacy). The diesel leak detection system was discontinued in August 1990, when a packer was installed at a depth of 3,940 feet below the Kelly bushing. The packer is located approximately 40 feet above the bottom of the injection string. The annulus is now filled with water (treated with corrosion inhibitor and biocide), under a continuous regulated nitrogen pressure of 150 to 160 psig, and is monitored as before.

The well injects into the Arbuckle Formation at depths between 3,978 and 4,646 feet below the ground surface. Wastewater injection is by gravity flow from a surface surge

tank. The operating water level in the well is approximately 250 feet below ground surface.

The UIC well is regulated by the Kansas Underground Injection Control Program (Permit No. KS-01-173-001). Permit restrictions are:

UIC PERMITTED CONCENTRATION RESTRICTIONS

<u>Parameter</u>	<u>Restriction</u>
pH	2.0-11.3
Total organic carbon	≤35,000 mg/l
Total organic halogens	≤10 mg/l
Toluene	≤1,000 mg/l
Nickel	≤1.3 mg/l
Benzene	≤0.66 mg/l
Acrylonitrile	≤4 mg/l
Chloride	no limit
Temperature	no limit

1.3.2 Former Process Operations

The production process used by Abbott involved batch hydrogenation of raw materials in several reaction vessels. The resulting chemical mixtures were then distilled. The higher and lower boiling point fractions were normally by-products and the intermediate fractions were products. The higher and lower boiling point by-product fractions were recycled, burned in the plant's boiler, or shipped off-site for controlled disposal.

Approximately 40 different chemicals were produced over time in the following three product categories:

- Industrial amines;
- Pharmaceutical intermediates; and
- Other industrial chemicals.

An example of industrial amines is cyclohexylamine, used as an intermediate by others in production of final products. An example of a pharmaceutical intermediate is diethyldipropylmalenate. In summary, the materials produced by Abbott were intermediate materials used by Abbott and by other manufacturers to produce final products.

1.3.3 Process Environmental Control Facilities And Operations

The various categories of wastes and the environmental control facilities used for each waste category were:

<u>Waste</u>	<u>Environmental Control Facility</u>
Wastewater	Evaporation pond Evaporation lagoon Septic tank and drain field UIC well NPDES discharge
Process by-products, used filters, and solvents	Drum Storage Pad

Table 2 is a summary of each of the waste disposal facilities used for environmental control.

The following is a discussion of each of the wastes and waste control facilities.

1.3.3.1 Wastewater

The sources of process wastewater were:

- Wash down water;
- Process generated water;
- Steam condensate;

- Cooling water;
- Cooling tower blowdown;
- Water softener regeneration water;
- Sanitary sewer wastewater; and
- Boiler blowdown.

All wastewater was collected by the plant sewer and sump system. The wastewater contained trace amounts of raw materials, products and by-products (KDHE, 1988). Table 3 lists the chemicals found in the wastewater.

Wastewater was discharged to the evaporation pond from plant opening in 1960 until 1981. The majority of the organic loading to the pond was estimated to be ammonia and amines. Estimates for the years 1979 and 1980 are (KDHE, 1988):

ESTIMATED ORGANIC WASTE DISPOSAL TO EVAPORATION POND		
<u>Waste Chemical</u>	<u>Year</u>	<u>Yearly Discharge Amount to Evaporation Pond (Tons/Year)</u>
Total organic loading	1979	150 to 175
Ammonia	1980	55 to 110
Dimethylamine	1980	45 to 50
Monoethylamine	1980	20 to 25
Monomethylamine	1980	<u>1 to 2.5</u>
Total organic loading	1980	121 to 187.5

TOTAL WASTEWATER DISPOSAL TO EVAPORATION POND		
<u>Year</u>	<u>Tons</u>	<u>Million Gallons per Year at Specific Gravity of 1.0</u>
1960 to 1975	10,000	2.4
1975 to 1980	20,000	4.8

Wastewater was discharged to the approximately 5-acre evaporation lagoon beginning in 1981. The design capacity was 8.25 million gallons and it was constructed with a clay liner and leachate collection system. Collected leachate was pumped back into the lagoon for evaporation. Drawing 6 shows the piping for the lagoon leachate collection system, extraction wells, and injection well.

Wastes present in the water discharged to the evaporation lagoon included acetates, ammonia, amines, cyclohexanol, and cyclohexanone. The wastewater was not considered a hazardous waste by USEPA Region VII or KDHE.

Yearly wastewater disposal for the years 1981 through 1984 was reported as (KDHE, 1988):

YEARLY TOTAL WASTEWATER DISPOSAL TO EVAPORATION LAGOON		
Year	Tons	Million Gallons at Specific Gravity of 1.0
1981	54,351	13.0
1982	31,510	7.6
1983	32,476	7.8
1984	39,511	9.5

Abbott (and later Air Products) made process and wastewater system changes to reduce the volume and the organic load to the lagoon. The evaporation lagoon was closed in 1986. Liquid remaining in the lagoon was disposed of by injection into the UIC well.

Wastewater was injected down the UIC well after the evaporation lagoon was closed in 1986. The only exceptions were cooling tower blowdown water and water treatment system regeneration water, which were discharged through an NPDES discharge point. The NPDES discharge could not be used during certain weather conditions. During these conditions, the NPDES wastewater was sent to the lagoon or was injected into the UIC well after the lagoon closure.

The plant's sanitary sewer was discharged to a septic tank and lateral drain field until 1981, when it was rerouted to the evaporation lagoon. When the evaporation lagoon was closed in 1986, sanitary sewer wastewater was discharged to the UIC well.

The wastewater system is shown schematically in Drawing 7 for the periods prior to 1981, 1981-1986, and after 1986. The volume distribution between the NPDES discharge and the flow to the UIC well is unknown. It is important to note that Abbott's responsibility with the operation portion of the Site ceased in July 1985.

1.3.3.2 Drum Storage Pad

Waste process by-products (higher and lower boiling point materials from distillation process) which were not recycled during the manufacturing process were drummed and stored on the Drum Storage Pad. The drummed by-products were ultimately either recycled in the process, sold, or used as boiler fuel.

Used filters and waste solvents were also drummed and picked up by waste disposal firms. These were also considered RCRA wastes (wastes solvents F003 and F005). Both the drummed filters and waste solvents were stored on the Drum Storage Pad for pick up by the waste disposal firms.

In summary, drummed wastes stored on the Drum Storage Pad were (KDHE, 1988):

Waste	USEPA Hazardous Waste Identification Number
Ignitables from alkylamine distillation	D001
Ignitables from ester alkylation distillation	D001
Corrosives from amine and ester production	D002
Spent methanol solvent	F003
Spent toluene solvent	F005
Spent filter cartridges containing toluene	F005

1.3.3.3 Deep Injection Well

The UIC deep injection well influent consists of extracted groundwater and leachate from the sump of the closed evaporation lagoon. During the closure of the evaporation lagoon, the UIC well was used to dispose of residual lagoon and sump fluids. The well is infrequently used by Air Products as an emergency backup when Air Products UIC injection well is inoperable (KDHE, 1988). During Air Products' use, groundwater from the Abbott extraction well system continues to flow at normal rates to the UIC well. Air Products flow stream is controlled so the total flow does not exceed the Abbott well capacity.

The volume of water injected per year for the period 1981 through 1990 was (KDHE, 1988):

YEARLY TOTAL WASTEWATER DISPOSAL UIC WELL		
Year	Tons/Year	Million Gallons at Specific Gravity of 1.0
1981	92,740	22.2
1982	250,350	60.0
1983	206,350	49.5
1984	292,605	70.1
1985	Data Not Available	
1986	211,380	50.6*
1987	323,390	77.4
1988	310,390	74.3
1989	283,230	67.8
1990	277,700	64.8

Notes: Data not available for 1985.

*Instrument failure affected readings for part of year in 1986.

1.3.4 Closure of Waste Disposal Facilities

All of the SWMUs have been closed except the UIC well. Only one facility, the Drum Storage Pad, was RCRA regulated. A full discussion of Facility closure is contained in

the Current Conditions Report (WCC, 1990b). The following is a summary of each Facility closure. A more detailed summary for each closure operation is presented in Section 4.2.1.7.

1.3.4.1 Evaporation Pond

The pond was closed in 1981. A discussion of the closure is contained in the Current Conditions Report (WCC, 1990b). Pond sediments were tested for EP Toxicity, found to be below action levels, and were left in place. Any liquid remaining in the pond was allowed to evaporate prior to closure. Closure was accomplished by pushing in the berm, and capping the pond with an 18-inch thick clay cap and a 6-inch thick soil cover. An asphalt surface seal was later constructed over the pond to further reduce infiltration.

1.3.4.2 Evaporation Lagoon

Lagoon closure began in 1986 and was complete in 1987. The Current Conditions Report (WCC, 1990b) contains the closure plan and a certificate of closure. Liquid remaining in the lagoon was sampled and then disposed of in the UIC well. The lagoon sediment was tested for:

- Volatile organic priority pollutants;
- Base-neutral priority pollutants;
- Acid extractable priority pollutants;
- Pesticides;
- Dioxins; and
- Heavy metals.

The compounds above detection limits were:

- Acrylonitrile

- Benzene
- Toluene

Closure was accomplished under the direction of KDHE.

The sides of the lagoon were pushed in and the lagoon was capped by a 2-foot thick clay seal followed by a soil cover. The leachate collection system was left in place and collected leachate continues to be disposed of in the UIC well. Abbott submitted a closure report to KDHE.

1.3.4.3 Drum Storage Pad

The area was closed in 1986 by removing all drummed wastes followed by power washing of the concrete slab. Wash waters were collected and tested for:

- Ignitability;
- Toluene; and
- Methanol.

All test results were negative. The containment dike was pushed into the containment ditch and the disturbed area was revegetated. The area was considered "clean-closed" because there was no evidence of residual contamination. The closure certification and the KDHE release from financial and liability assurance requirements is contained in Appendix C of the Current Conditions Report (WCC, 1990b).

1.3.5 Past Product and Waste Spills and Discharges and Actions in Response to Spills and Discharges

There are no records of any surface overflow of the evaporation pond or the evaporation lagoon during their respective operation periods (KDHE, 1988).

The plant process sewers were inspected in 1979. Several leaks were found and repaired in 1979.

The UIC well is inspected regularly. There is no record of leakage or overflows from the well (KDHE, 1988).

Interviewed Abbott personnel reported rare occurrences of liquid and vapor releases from ruptured disk seals, reactor vessels, and rail car loading areas. No documentation could be found in Abbott's files which recorded these releases.

The Drum Storage Pad is the only facility with a record of waste releases. A KDHE inspection in 1982 found some leaky drums on the concrete storage pad which were subsequently cleaned up by Abbott. The KDHE inspection report referred to this as a small spill and not a major release. There is no evidence of any major spills at the Drum Storage Pad (KDHE, 1988).

On March 9, 1992, groundwater was inadvertently discharged by a contractor from extraction well EW-10 to a nearby roadside ditch. This release occurred during a maintenance program to increase the attainable discharge of well EW-10. Well EW-10 had been experiencing steady declines in production caused by what appears to be bacteria growth in the well. At the end of acidification treatment of the well, approximately 600 gallons of water was mistakenly discharged into the roadside ditch. Upon notification that discharge to the ditch was inappropriate, the flow from the well was diverted to the existing deep injection well. Because this was an unauthorized release, the event was reported to KDHE and EPA.

Although the entire discharge was contained within the ditch, additional precautions were taken to prevent surface migration of the water. Samples were collected and analyzed for volatile organic chemicals (VOCs, EPA Method 8010). The analytical results indicated that VOC concentrations were either non-detect or below the 10 mg/L RCRA action level for all constituents.

After the results of the water sampling were reviewed by Abbott, KDHE and EPA, permission was granted by KDHE and EPA to discharge the water to the injection well. After the water was removed, samples were collected from the underlying soil and analyzed for VOCs. No residual soil contamination was detected.

In summary, the only historical recorded release was a small leak from some drummed wastes on the Drum Storage Pad which was cleaned up.

1.3.6 Previous Studies

Between March 1979 and November 1989, nine reports were prepared for Abbott Laboratories by companies other than WCC. Brief summaries of these reports are presented in chronological order below.

Abbott Laboratories Groundwater Study, Wilson Laboratories, March 1979

This study summarized the efforts to determine the extent and nature of groundwater contamination with organic chemicals at the Facility. Methods were developed to perform low level analysis of cyclohexanone and nine primary and secondary amines by gas chromatography (primary and secondary amines are defined in Section 6.0). Results were presented from samples collected from Abbott's south well and evaporation pond influent.

Abbott Laboratories Wichita Plant Water Quality Management Program Engineering Report, Ultimate Disposal Alternatives, Wilson Laboratories, March 1980

The status of Abbott's water quality management program was discussed and four disposal scenarios were presented for wastewater streams. Scenarios include various combinations of surface discharge, evaporation lagoon disposal, and deep well injection disposal. The recommended scenario suggests boiler blowdown and water softener regeneration fluids be diluted to NPDES permitting levels and discharged to the surface with an optional bypass to the evaporation pond. Sanitary waste and process wastewaters would be subjected to minimal biological treatment to reduce organic content to a level that would permit surface disposal under NPDES. If organic treatment fails to reduce organic content, process waters would be routed to a 7-acre evaporation lagoon.

Environmental Control Program, Wilson Laboratories, April 1980

The water quality conditions at that time and water quality programs in progress were documented. A plan for the development and implementation of the following programs was outlined.

- Pumping of contaminated groundwater to a spray irrigator to evaporate and degrade amines.
- Removal of amines, ammonia and miscellaneous organic liquids by process exhaust incineration.
- Construction of a 5-acre waste evaporation lagoon.
- Prevention of sewer leakage.
- Construction of railhead drainage and collection facilities.
- Construction of a process water supply system.
- Development of boiler and cooling tower blowdown disposal plan.
- Closure of existing evaporation pond.
- Continuation of groundwater analytical monitoring on a quarterly basis.

Disposal Well System Evaluation, Ken E. Davis Associates, February 1986

The Abbott deep injection well system was inspected and tested to investigate anomalous pressure increases. The investigation determined that high concentrations of calcium carbonate were plugging the well bore. Acidation was recommended to improve the current conditions.

Abbott Laboratories, Wichita, Kansas, Industrial Wastewater Surface Impoundment Closure Conceptual Plan, J.C. Butler Associates, Inc., July 1986

This report was a conceptual plan for closure of the waste evaporation lagoon in operation until May 1986. A detailed plan for lagoon closure was proposed to the KDHE for approval.

Abbott Laboratories Deep Disposal Well Closure Plan J.C. Butler Associates, Inc., December 1987

This report was a conceptual plan for closure of the UIC deep injection well by Abbott after compliance with the UIC program and well permit requirements.

RCRA Facility Assessment, KDHE, April 1988

This report was a Facility Assessment prepared by KDHE after a Facility inspection and sampling that focused on the evaporation pond and lagoon, deep injection well, drum pad, waste pile, and contaminated groundwater.

Groundwater Sampling and Analysis Plan, Corporate Environmental Services (Abbott Laboratories), May 1989

This plan represented part of Comprehensive Monitoring Evaluation of the Facility being performed by the KDHE. This plan addressed sample collection procedures, sample preservation and handling, sample documentation, analytical methods, frequency of analysis, record keeping and reporting of results to KDHE.

Abbott Laboratories Operation and Maintenance Manual for the Groundwater Extraction and Injection System at the Wichita, Kansas Facility, J.C. Butler Assoc., Inc., November 1989

This manual was prepared for system operation and maintenance for the Abbott extraction and deep injection system used to control off-site migration of contaminants.

SUMMARY OF INVESTIGATION ACTIVITIES

This section will discuss the investigations which were performed as part of the RFI. These investigations included:

- Constructing additional monitoring well clusters to collect additional water quality and geologic data;
- Drilling geotechnical borings to investigate the unconsolidated sediments above the water table in the vicinity of the source areas;
- Collecting shallow soil samples, leachate samples, and deep soil samples to characterize the source areas;
- Drilling and packer testing a 50-foot core into the Wellington Shale formation beneath the Facility to characterize the lower confining layer; and
- Conducting groundwater and surface water surveys to identify current and potential future impacts in the area.

The investigations described herein were conducted in accordance with the USEPA-approved RFI Work Plan (WCC, 1991b). The results of the investigation are presented in Sections 4.0, Physical Results, and 5.0, Analytical Results.

2.1 MONITORING WELL CONSTRUCTION

A monitoring well network has existed at the Facility since 1979. Monitoring wells 1, 3D, 4S and 4D; 5S and 5D; 8S and 8D were logged and installed in September of 1979. A second round of well installations occurred in 1983, when monitoring wells 101S, 101I; and 101D, 102S; and 102D, 104, 105S, and 105D were installed. Extraction well EW-17 was also installed at this time. Well locations are shown in Drawing 8, and boring logs are included in Appendix A. Table 4 summarizes monitoring well specifications with information such as well diameter, screen length, sand unit screened and top of casing elevations.

A review of the well logs show that the unconsolidated deposits overlying the bedrock consist of interlayered sands and clays. The separate sand layers are labeled S-1 through S-4, with S-4 being the shallowest unit. The sands are separated by three clay layers, labeled C-1 through C-3, with C-3 being the shallowest clay layer. Most of the shallow monitoring wells, designed as "S" wells, are screened in the S2 and S3 sand units. The majority of the deep monitoring wells, designated as "D" wells, are screened in the S1 sand unit.

To further refine the hydrogeological understanding of the area, two monitoring well clusters (106 and 107) were installed in May 1991 as part of the RFI activities. An additional monitoring well cluster (108) was installed in September 1991. Numerous water level measurements in the existing monitor wells suggested that ground water flow across the Facility was in an east-southeastern direction. To confirm these findings, monitor wells 106S and 106D and 107S and 107D were located east of the Facility and monitoring wells 108S and 108D were located southeast of the Facility (Drawing 8).

Wells 106D, 107D, and 108D were completed in the lowest sand layer encountered (S-1). Wells 106S, 107S, and 108S were completed in the unit believed to be a combination of S-2 and S-3. The three deep wells were continuously logged during construction by a field geologist to accurately locate the sand units of interest. Monitoring well boring logs and well completion reports are included in Appendix A.

Following well development, initial ground water samples were taken in all six wells. Four monitoring wells (106-D, 106-S, 107-D, and 107-S) were added to the second quarterly ground water sampling event to investigate potential plume migration in the easterly and southeasterly direction. Monitoring well cluster 108 will be added to the quarterly groundwater sampling program starting with the fourth quarter (December) 1991 event. In addition, water level data collected from these wells were used to refine concepts of local hydraulic gradient temporal changes.

2.2 GEOTECHNICAL BORINGS

To characterize the unconsolidated deposits above the water table in the vicinity of the evaporation pond and lagoon, three borings were advanced to an approximate depth of 49 feet. The location of the three geotechnical borings (labeled B-1, B-2 and B-3) are shown in Drawing 9, and the boring logs are included in Appendix A.

Each boring was continuously logged, photographed, sampled, and USC classified in the field. The soil samples were sent to a certified geotechnical laboratory and the following testing was performed:

- Grain Size Analysis
- Specific Gravity
- Atterberg Limits
- SCS Soil Classification
- Cation Exchange Capacity (CEC)
- pH
- Total Organic Carbon (TOC)

In addition, two samples from boring B-3 representing sand layer S-4 and the clay layer C-3 were collected in sealed plastic liners that allowed additional testing including:

- Initial Moisture Content
- Dry Density
- Total Porosity

Results of the geotechnical laboratory work are summarized in Table 5, field and laboratory data are included in Appendix B. The geotechnical results are discussed in Section 4.1.1.3, Unit Classification.

2.3 WASTE SOURCE CHARACTERIZATION

2.3.1 Objectives and Approach

The objectives of the waste source characterization were to conduct a focused investigation of the closed lagoon and pond to characterize the waste and source areas sufficiently to support the CMS and to update the current characterization of the units. Chemical analyses of the groundwater from existing Abbott monitoring wells indicate the presence of Abbott constituents. The waste source characterization studies were designed to identify those constituents present in the Facility waste sources, and identify those in the unsaturated zone below the waste sources, so that a comparison could be made to those present in the groundwater below the Facility. Chemical analyses of groundwater from existing Abbott monitoring wells indicate the presence of constituents which are not thought to be part of Abbott's waste. The waste source characterization was also designed to identify mutual constituents; i.e., those contributed to the groundwater by Abbott's waste sources which are also present in the plume from an upgradient source.

Shallow waste source characterization consisted of leachate samples collected from the closed evaporation lagoon, and two soil/waste samples taken from the closed evaporation pond. The leachate collected at the lagoon is regarded as a representative composite sample of the waste constituents in the clay liner overlying the leachate collection system.

Samples were collected below the interface of the clay liner and backfill in the pond and analyzed for Abbott Constituents and selected Appendix VIII constituents as noted in Table 1-2 of the USEPA-approved RFI Work Plan (WCC, 1991b). Leachate samples were collected at the sump of the lagoon leachate collection system. The leachate samples were analyzed for Abbott Constituents as well as the selected Appendix VIII constituents shown on Table 1-2 of the RFI Work Plan.

The analytical results of these samples provided the basis for the analyses which were conducted on the subsurface soil samples directly below the units (deep waste source characterization).

Two deep waste source characterization boreholes were installed, one each beneath the pond and the lagoon by means of slant hole drilling. Three samples were collected in each deep waste source characterization borehole. The three samples were located:

- Approximately 10 vertical feet below the backfill/clay liner interface;
- Midway between the first deep sample and the estimated depth to groundwater; and
- Approximately 5 vertical feet above the estimated groundwater level in the vicinity of the borehole.

The deep waste source characterization samples at each unit were analyzed for only those constituents that were detected in the shallow waste source characterizations (the shallow borings for the pond and the leachate samples for the lagoon).

2.3.2 Shallow Waste Source Sampling

Three shallow borings were advanced with a hand auger through the asphalt cap covering the former evaporation pond (Drawing 9). Information available through interviews with Abbott personnel indicated that the evaporation pond depth was approximately 10 feet below ground level. Because this depth was uncertain, borings EP-1 and EP-2 were augered to a depth of 9.5 feet, and EP-3 to 12 feet in 1-foot intervals in an attempt to detect the fill-clay interface at the base of the pond. The borings were logged continuously, but no distinction could be made between the fill, clay and undisturbed soils. Once the borings were completed, the holes were immediately backfilled and re-capped with asphalt.

Analytical samples were collected from borings EP-1 and EP-2 by compositing the auger cuttings throughout the entire depth of the hole. Boring EP-3 was augered to confirm the difficulty in detecting the fill/soil interface, and therefore, no sample was taken in EP-3. Samples were analyzed for selected Appendix VIII and Abbott-specific constituents as described in the USEPA-approved Work Plan (WCC, 1991b). The analytical results of the shallow waste source samples are summarized in Table 6 and the analytical laboratory report is included in Appendix C.

Extreme care was taken to detect the fill-clay interface at the time of the sampling, but differentiation was not possible. The borings were immediately backfilled and capped with asphalt following sampling, to preclude leakage through the liner.

2.3.3 Leachate Collection System Sampling

The leachate sampling program was designed to obtain aqueous samples from the active sump in the closed lagoon at the Facility. The leachate collection system is located in a sand layer located between two clay liners at the bottom of the lagoon (Drawing 11). Leachate containing water-soluble chemicals moving through the upper clay liner migrates into the sand layer and collection piping above the underlying clay layer. The upper clay-sand interface has a network of perforated pipes installed to collect leachate and transport it to the sump (Drawing 6).

Leachate samples were collected from the standing water in the active sump located at the northwest corner of the former lagoon (Drawing 6). Samples (L-1 and duplicate L-2) were analyzed for Abbott amines and selected Appendix VIII constituents as presented in the USEPA-approved Work Plan. A summary of results is included in Table 7, and the analytical laboratory report is included in Appendix C.

2.3.4 Deep Waste Source Sampling

Two deep waste source characterization borings were drilled: one each at the pond (WS-01) and the lagoon (WS-02). Sample locations for the pond are shown in Drawing 10 and sample locations for the lagoon are shown on Drawing 11. A Slant-hole, 45 degree, hollow-stem auger drilling technique was used to prevent breaching the closed lagoon's leachate collection system and the closed pond's clay liner.

A total of three analytical samples were collected from each boring, at depths between the bottom of SWMU's and the water table. The three discrete samples were collected and logged at approximately 20, 35 and 45 feet vertical depth below the surface. The samples taken were analyzed only for the constituents detected in either the pond shallow waste source soil samples or the lagoon leachate collection system. Analytical

results are summarized in Table 6, and Appendix C contains the analytical laboratory report. The waste source characterization boring logs are contained in Appendix D.

2.4 BEDROCK FORMATION TESTING

2.4.1 Bedrock coring

An investigation of the degree of fracturing and channeling in the Wellington Formation was performed to determine the potential for contaminant migration through the bedrock. A test hole was drilled, cased and the annular space cemented to the surface to allow coring, visual inspection and pressure testing (to calculate hydraulic conductivity) of the upper 50 feet of the Wellington. The test hole was located adjacent to existing monitoring wells 8-D and S (Drawing 9).

An 8-inch borehole was drilled without sampling to a depth within 3 feet of the bedrock surface, 121 feet below ground surface (bgs). A split-spoon sampler was driven into the Wellington Shale until refusal. Visual inspection of the sample confirmed the presence of the shale. Steel casing, 4.5 inches O.D. (nominal) with a drillable up-stab, flow-jet shoe was set and cemented to the surface.

The shale bedrock below the casing was cored 50 feet (from 123-173 feet bgs), using an NX rock coring sampler. Sample recovery was 38.5 feet (77 percent), and 11.5 feet of core was not recovered. The recovered cores were logged in detail and are included in Appendix E.

The core samples contained a variety of gray and olive-gray shales and mudstones with several thin limestone beds (2-12 inches thick). Gypsum and anhydride occurred at depths starting at 145 feet bgs, as very thin layers, seams and partings. The gypsum beds are most common in the lower part of the formation and the anhydride occurs with shale in a thick salt bed in the middle of the formation. Solution cavities and very friable shales were detected in the lower portion of the borehole. Discontinuities along the planes of bedding that intersected small joints were observed in the shales and limestones at several levels. Commonly, these joints and fractures were sealed with

secondary calcite and gypsum. As a result of the numerous fractures, approximately 2100 gallons of water was lost into the formation beginning at 145 feet bgs.

After completion of the coring, the water level in the borehole was measured at 46 feet bgs. In the adjacent monitor wells 8-S and 8-D, the measured water levels were 49.08 and 48.97 feet bgs. To verify the Wellington borehole water level, approximately 30 gallons of water was bailed and the water level was then allowed to stabilize. Within 30 minutes however, the water level recovered to 46.25 feet bgs, indicating that water within the Wellington Formation exists under artesian conditions. Given that the casing was fully cemented from the top of the Wellington formation, and the observation during the packer test (see Appendix E) that no flow could be induced in the upper interval tested, there would be no contribution of groundwater from the overlying unconsolidated aquifers into the borehole.

2.4.2 Packer Test

Packer testing was performed to physically measure the hydraulic conductivity within the cored interval. For the theory behind the method, the reader is referred to Hvorslev (1951).

In general, a packer test involves isolating a portion of the borehole with one or two inflatable rubber glands. Pressure transducers are placed in the sealed interval, above and below the packers to continuously monitor the pressure changes that will occur. Water is then pumped into the sealed interval, at a measured rate of flow, until steady state flow and pressure is maintained.

In the Wellington Formation, four packer tests were performed to determine the average hydraulic conductivity in the upper 50 feet of shale. Drawing 12 shows the intervals tested and the permeability results. The range of values throughout the cored interval was 1.3×10^{-6} to 8.6×10^{-4} centimeters per second (cm/sec). The test performed over the entire 50-foot section showed an average hydraulic conductivity of 8.6×10^{-4} cm/sec. Refer to Appendix E for the calculations, data and detailed results of the tests.

2.5 SURFACE WATER USE SURVEY

A surface water use survey was conducted to identify and characterize the surface water bodies within a one square-mile radius of the Facility. The RFI Work Plan scope of work for the surface water survey included the following tasks:

- Identification of surface water features, both natural and man-made;
- Identification of runoff patterns from the Facility; and
- A visual assessment of sediments for contamination from off-site surface water runoff.

Surface water features and runoff patterns were identified using maps (USGS topographical) and aerial photographs of the Facility area. This information was verified during the RFI field investigation, including a reconnaissance of the area adjacent to and surrounding the Facility. Runoff patterns were not assessed during a storm event.

The results of the surface water use survey are summarized in Section 4.2.3.

2.6 GROUNDWATER USE SURVEY

A groundwater use survey was conducted within a 1.5 mile radius of the Facility. The purpose of the survey was to assess the impacts, if any, that man-made influences have on the hydrogeology of the area. The survey included the following items.

- A review of state and county records;
- An identification of groundwater uses (residential and commercial) and pumpage schedules; and
- A field reconnaissance to locate wells and features that may affect the hydrogeology, such as ditches, buried pipelines, drains, and outfalls.

The review of well records and identification of groundwater uses was completed in conjunction with other RFI activities. The results of the groundwater use survey are summarized in Section 4.1.1.5.

PHYSICAL CHARACTERIZATION

3.1 PHYSIOGRAPHY

The Facility lies within the Arkansas River lowlands section of the Central Lowlands Physiographic Province. The topography is characterized by the extreme flatness of a broad river valley and the gently rolling slopes rising to the uplands adjacent to the valley. Ground surface elevation ranges from about 1300 to 1310 feet. Elevations are relative to National Geodetic Vertical Datum (NGVD).

3.2 METEOROLOGY AND CLIMATOLOGY

The Facility is located in southeast Kansas in a climate region classified as humid continental. The Facility overlies in the Central Great Plains where masses of warm moist air from the Gulf of Mexico collide with cold, dry air from the Arctic region to create a wide range of weather the year around. Historically, southeast Kansas undergoes warm rainy summers contrasting with mild winters with brief periods of very cold weather.

The nearest meteorological station to the Facility is Wichita, Kansas located just over 1,300 feet above mean sea level. (United States Department of Commerce, 1991). This meteorological station is approximately four miles north of the Facility.

Annual precipitation for Wichita is shown in Drawing 13. The average annual precipitation at Wichita from 1954 to 1990 was 29 inches. Larger precipitation amounts were generally observed during the months of April through September. Thunderstorms occur mainly during the spring and early summer. The storms can be severe and can cause damage from heavy rain, large hail, strong winds and tornadoes.

The average annual temperature is 57 degrees Fahrenheit (°F) for Wichita. Drawing 14 shows average monthly temperature distribution for Wichita.

The average monthly temperature ranges from 31°F in January to 81°F in July. Temperatures above the average are recorded from May through October, while the rest of the year are below the average. Record highest and lowest temperatures have been recorded in the months of July, 113°F maximum, and February, 21°F below zero minimum.

The yearly average wind speed is 12 mph. Prevailing wind direction is reported south with the windiest months March and April with a mean speed of 14 miles per hour (mph). Lower than average winds occurred from June through January blowing south.

The relative humidity ranges yearly from 44 to 83 percent. Yearly average barometric pressure is 968 millibars.

Strong north winds often occur with the passage of cold fronts from late fall through early spring. Extremely low wind chill factors are experienced with very cold outbreaks during the mid winter.

3.3 GEOLOGY

3.3.1 Regional Geology

Lower Permian sedimentary rocks of the Cimmeronian Stage form the uppermost bedrock in Sedgwick County. The Wellington Formation, which is poorly exposed due to low resistance to weathering and low topographic relief, is the uppermost bedrock in the eastern two-thirds of the county. In the western third of the county, the Ninnescah Shale conformably overlies the Wellington Formation. The Ninnescah Shale is better exposed than the Wellington Formation due to greater topographic relief in the western portion of the county. Both units dip approximately 20 feet per mile to the west-southwest. The stratigraphic section for Sedgwick County, Kansas, is depicted in Drawing 15.

Thick, unconsolidated Tertiary and Quaternary deposits lie within a depression on the bedrock surface in the Arkansas River Valley. The depression follows the subcrop of the easily dissolved Hutchinson Salt Member of the Wellington Formation. The

Hutchinson Salt is approximately 350-feet thick where it has not been eroded and is generally in the middle of the Wellington Formation. The Pliocene Ogallala Formation lies within the northern half of Sedgwick County and is the oldest, unconsolidated deposit present. Undifferentiated Lower Pleistocene, Nebraskan, and Kansan glacial-derived deposits overlie the Ogallala in the Arkansas River Valley north of Wichita, and lie on Permian rocks south of Wichita. These deposits are overlain by Illinoian terrace deposits in the western portion of the Arkansas River Valley and the northern portion of the Ninnescah River Valley. In the upland areas, Illinoian to Recent loess and colluvium overlie the Nebraskan and Kansan deposits. Wisconsinian to Recent alluvium and terrace deposits overlie the Illinoian terrace deposits in the eastern portion of the Arkansas River Valley and in other major stream valleys. Unconsolidated deposits are the major source of groundwater in central Sedgwick County.

Sedgwick County lies within the Sedgwick Basin, which is a southerly plunging shelf-like extension of the deeper Anadarko Basin to the south. The Sedgwick Basin is bounded to the east by the Nemaha Anticline, to the west by the Pratt Anticline and to the north by an indistinct saddle marking the boundary of the Salina Phanerozoic Formation. These sedimentary rocks reach thicknesses of as much as 5,500 feet in the deepest parts of the Sedgwick Basin (Lane and Miller, 1965b).

Paleozoic rocks in Sedgwick County are roughly 4,000 to 5,000 feet thick. The Cambro-Ordovician Arbuckle Group overlies the Precambrian and consists of cherty dolomite and is at least 700 feet thick in the vicinity of the Facility. The Arbuckle Group is overlain by the Ordovician Gimpson Group, the Viola Limestone, and the Maquoketa Shale, respectively. Collectively, these units are approximately 200 feet thick in Sedgwick County and are overlain by a thin bed of the Devonian-Mississippian Chattanooga Shale. Roughly 400 feet of Mississippian carbonates overlie the Chattanooga and 2,000 feet of Pennsylvanian cyclothermic shales and limestones unconformably overlie the Mississippian. Approximately 800 feet of similar cyclothermic shales and limestones of the Gearyan Stage of the Lower Permian Series overlie the Mississippian Units. The Gearyan Stage is overlain by anhydride, gypsum, and carbonate-bearing shales of the Cimmaronian Stage, which includes the Wellington Formation and the Ninnescah Shale (Zeller, 1968 and Merriam, 1983).

The Facility is located on the northwest limb of the Bluff City-Valley Center-Ebling Anticline. No known surface faults are present within Sedgwick County. The area is considered seismically stable with low risk of earthquake damage due to its location near the Nemaha anticline. A few minor earthquakes have occurred along the Nemaha anticline.

3.3.2 Facility Geology

The uppermost bedrock unit beneath the Facility is the Wellington Formation. The Wellington consists mainly of calcareous, gray and blue-gray shale containing thick beds of salt and thin beds of gypsum, anhydride, and impure limestone. Gypsum beds are most common in the lower part of the formation. The Hutchinson Salt Member lies in the middle of the Wellington Formation but has been removed by solution in the eastern two-thirds of Sedgwick County, and partially removed in the area beneath the Facility. The Hutchinson Salt member was not encountered during the bedrock coring performed as part of the RFI field activities. Within five to ten miles west of the Facility, the Hutchinson Salt thickens to near its uneroded thickness of approximately 350 feet. The Wellington is approximately 400 feet thick beneath the Facility, and ranges in thickness from 80 feet near the east county line, where it is partially eroded, to 550 feet near the west county line, where the entire thickness of salt and gypsum are present.

The Wellington is considered to be the lower confining layer for the unconsolidated deposits underneath the Facility. The unconsolidated deposits are the major water producing units in central Sedgwick County. Approximately 100 to 150 feet of Pleistocene to Recent deposits overlie the Wellington in the vicinity of the Facility. The Pliocene-Pleistocene Ogallala has not been identified in the southern part of Sedgwick County, including the Facility. The lowermost unconsolidated deposits beneath the Facility are the Lower Pleistocene, undifferentiated Nebraskan and Kansan deposits which are overlain by Illinoisan terrace deposits.

The Nebraskan and Kansan deposits consist mainly of tan, sandy silt, sand, and fine to medium grained gravel. A few miles south of the Facility, a layer of volcanic ash known as the Pearlette Ash Bed was encountered in these deposits. The Illinoisan terrace

deposits consist of gray, sandy silt, sand, and fine to medium grained gravel. Both units thin to the southwest.

3.3.3 Soil

Two soil types found at the Facility are the Tabler Silty Clay Loam and the Blanket Silt Loam (USDA, 1979). The Tabler typically has a permeability of 0.2-0.6 inches/hour (1.4×10^{-4} to 4.2×10^{-3} cm/sec) in the top nine inches, and 0.06 inches/hour (4.2×10^{-4} cm/sec) below nine inches. The soil is capable of storing large quantities of water, but releases the water slowly. A high perched water table at a depth of 2.5 to 3.5 feet bgs commonly forms from October through April. The Blanket has a permeability of 0.6 to 2.0 inches/hour (4.2×10^{-3} to 1.4×10^{-3} cm/sec) above 14 inches in depth, and 0.3 to 0.6 inches/hour (2.1×10^{-4} to 4.2×10^{-3} cm/sec) below 14 inches.

3.4 HYDROLOGY

The following sections summarize the surface and groundwater hydrology of the areas surrounding the Facility.

3.4.1 Surface Water

The surface drainage of the area is to the Arkansas River and its tributaries. Dry Creek, an intermittent stream, lies approximately 1 mile to the southwest of the Facility. Dry Creek flows southward to Spring Creek which eventually flows into the Arkansas River by way of the Ninnescah River. The Ninnescah River is located approximately eight miles southwest of the Facility.

Much of the flat land near the Arkansas River is very poorly drained and artificial drains have been installed on much of the agricultural land (Lane and Miller, 1965a). A flood diversion system has been constructed around Wichita to alleviate recurrent flooding of the urban areas by the Little Arkansas and Arkansas Rivers. A portion of this floodway system, the Wichita Valley Center Floodway, lies about five miles to the east of the Facility. Drawing 4 shows the drainage features for surface water runoff around the Facility.

3.4.2 Groundwater

The unconsolidated deposits which overlie the Wellington Shale comprise the uppermost aquifer at the Facility. The Wellington Shale acts as a lower confining layer for the aquifer. Some water is available from the weathered portion of the Wellington, but it tends to be highly mineralized because of the evaporites present in the formation. The productivity of wells completed in the Wellington tends to be low (Lane and Miller, 1965a). Because of the low yield and generally poor water quality, most of the wells in the vicinity of the Facility do not generally penetrate far into the Wellington Formation (KDHE, 1988).

Although the unconsolidated deposits can generally be differentiated into separate sand and clay units, most wells completed into these deposits are not screened in any single stratigraphic interval. The water obtained from the formations is usually high in dissolved solids, but is suitable for most purposes. The water from the lowest portions of the aquifer may contain undesirable amounts of dissolved salt from the Wellington in the area of the Facility.

The aquifer at the Facility is generally comprised of two layers of higher and lower permeability, corresponding to sand and clay stratifications (Drawing 12). Monitoring well clusters have been installed by Abbott and others to monitor the groundwater because of the multi-layered aquifer. Regional groundwater flow is generally to the southeast, but localized, transient pumpage for irrigation, water supply and extraction wells disrupt the regional pattern.

4.1 ENVIRONMENTAL SETTING

4.1.1 Hydrogeologic Conditions

A summary of previous studies regarding the regional and Facility hydrogeology is contained in Section 3.4. The following sections enhance the body of information presented in Section 3.4.

4.1.1.1 Facility-Specific Geologic Conditions

At the Facility, 24 monitoring and extraction wells now comprise the groundwater monitoring network. In addition, numerous wells owned by Vulcan Chemicals, the Murray-Gill plant, and local individuals also contributed to the understanding of the local geologic and hydrogeologic conditions. The use of all boring logs available in and around the Facility gave a clearer, more detailed understanding of the local geology.

The underlying bedrock, the Wellington Shale, has been previously described in Section 2.4, Bedrock Formation Testing. The following discussion will focus exclusively on the unconsolidated deposits that comprise the ground water flow system underneath the Facility.

The unconsolidated deposits consist of interlayered sands and clays. The sands are generally fine to medium grained with some silt. The clay layers usually contain some silt and occasional sand lenses. The depositional environment was alluvial. Therefore, the beds may be laterally discontinuous.

In numerous borings made on the Abbott Facility and the surrounding area, four separate sand layers have been encountered. These have been labeled S-1 through S-4, with S-4 being the shallowest unit. The sands are in turn separated by three clay layers,

C-1 through C-3, (C-3 being the shallowest clay which separates S-4 from S-3). Drawing 16 depicts the typical cross-section of unconsolidated deposit nomenclature.

The generalization that the beds are continuous across the Facility is extended to all areas except where the beds are proven absent by boring logs. Drawings 17, and 18 depicts geologic cross-sections made from the boring logs of monitoring wells located along the southern and eastern border of the Facility. Drawing 8 depicts the geologic cross-section locations. Deviations from the generalization can be seen in these drawings. The most common examples are, the shallow sand S-4 is not always present, and S-2 and S-3 sometimes appear to combine into a single sand unit. This combination of the sand and clay layers has resulted in a interconnected and complex aquifer system.

4.1.1.2 Regional and Facility-Specific Hydrogeologic Conditions

Regional groundwater flow is generally to the southeast (Lane, 1965). Groundwater levels collected from the monitoring well network show that local or Facility-specific groundwater flow direction tends to be generally to the east adjacent to the Facility. Potentiometric maps have been constructed from groundwater elevations of the 22 (18 previous to the RFI field investigation) Facility monitoring wells. Six maps are presented (Drawings 20A through 22B) corresponding with the September 1991, December 1991, and March 1992 quarterly groundwater sampling events. Separate potentiometric maps are presented for the deep S₁ sand unit and shallower S₂/S₃ sand units. Additionally, drawings 23A and 23B present the vertical hydraulic gradients at the facility for the March 1992 sampling event. The hydraulic gradient for the area, based on the Potentiometric maps is approximately 3.0×10^{-4} ft/ft.

The depth to groundwater of the lower three aquifers (S-1, S-2, S-3) is generally 50-feet. There is, however, a perched aquifer associated with the S-4 sand unit adjacent to MW-101 monitoring well cluster. Clay unit C-3 located beneath sand unit S-4, possibly acts as an aquiclude preventing downward migration of the groundwater to the regional groundwater level.

The water levels measured in the Wellington Formation corehole were approximately 3 feet higher than the water levels in nearby monitoring wells completed in the overlying

unconsolidated formation. This suggests that an upward hydraulic gradient exists in the area beneath the Facility. This phenomenon has been observed in the area by others (Buddemeier et al, 1991) and has been suggested as a partial reason for the relatively unchanged regional water levels during the past 30 years.

Finally, a low lying area immediately south of the asphalt cap of the closed evaporation pond remains soft after adjacent lands have dried following a rain shower or other precipitation event. This may be indicative of the slow percolating soils near the closed evaporation pond.

Recharge and Discharge of Unconsolidated Sediments

Precipitation is the primary source of groundwater recharge in Sedgwick County (Lane and Miller, 1965a). Williams and Lohman (1949) estimated that recharge in the Arkansas Valley to be 20 percent of the precipitation, or an average of 320 acre-feet per year per square mile. Recharge of unconsolidated sediments also comes from subsurface inflow of groundwater upgradient. In previous studies, (Lane and Miller, 1965a) no attempt was made to compute the net quantity of inflow but compared to recharge from precipitation, it is probably insignificant.

Discharge from unconsolidated sediments occurs mainly by seeps in and along stream channels and by pumping of wells (Lane and Miller, 1965a). The quantity of seepage into streams is not known, but it is believed to be quite large. Most of the groundwater in this region moves towards the Little Arkansas and Arkansas Rivers.

Over a period of years, or a climatic cycle, the quantity of groundwater discharge is about equal to the quantity of recharge, although the balance may be upset locally in areas of heavy pumping, (Lane and Miller, 1965a).

4.1.1.3 Unit Classification

The sedimentary units described in previous sections by their nomenclature (i.e., C-1, S-1) are detailed as to their hydraulic conductivity, transmissivity, porosity, lithology, grain size and sorting characteristics in this section.

Hydraulic Conductivity

Values for hydraulic conductivity and transmissivity have been calculated for various formations using three test methods:

- Long-term constant rate of aquifer pumping tests;
- Slug tests; and
- Packer tests.

The analytical methods used and resultant calculations are tabulated in Tables 8 and 9 for the pumping tests and slug test results, respectively, which were performed as part of the RFI field activities. Generally, hydraulic conductivity and transmissivity values ranged from 80 to 172 ft/day (2.28×10^{-2} to 6.0×10^{-2} cm/sec) and 600 to 1,278 ft²/day (6.4×10^{-8} to 1.37×10^{-7} cm²/sec), respectively. This range derived from the aquifer pumping test, is thought to be a better indication of hydraulic conductivity than is determined using the Slug Test results (5.5 to 24.2 ft/day (1.94×10^{-3} to 8.53×10^{-3} cm/sec) and 40.8 to 181.1 ft²/day (4.00×10^{-9} to 1.90×10^{-8} cm²/sec), respectively). These values are typical for a fine to coarse sand aquifer (Driscoll, 1986).

The final analytical test method (Packer Test) was used to determine hydraulic conductivity for the upper 50 feet of the Wellington Formation. Values of hydraulic conductivity obtained from the packer tests range from 1.3×10^{-6} cm/sec and in the upper 7 feet of the Wellington Formation to 8.6×10^{-4} cm/sec. The latter more permeable packer test results represent a relatively more fractured section of the Wellington Formation. A summary of the packer test intervals and test results are presented on Drawing 12. These hydraulic conductivity values are typical for shale formations (Driscoll, 1986).

Porosity

Porosity values were derived using ASTM Method D854 on one sand and one clay unit. The samples were collected inside of a clear plastic tube placed inside of a 3 1/2-inch O.D. CME continuous sampler. The samples were sealed immediately upon retrieval

from the sampler and shipped to the geotechnical laboratory under chain-of-custody. Values of porosity ranged from 35 percent for a sand sample from unit S-3 in Boring B-3 to 47 percent for a sample from clay unit C-3 in Boring B-3. Both samples were located above the static groundwater level.

Lithology

The lithology of the discrete sedimentary unit is described by the boring logs from the RFI field investigation. However, boring logs from previous studies by others were used as needed to fill in necessary data gaps.

Eight units will be described, beginning from the uppermost topsoil encountered and continuing with increasing depth until the lowermost sand (S-1) is detailed. However, not all of the discrete units identified are present in the subsurface adjacent to the Facility. This is a function of the depositional nature of the alluvial deposits.

Generally, the uppermost topsoil is described as a medium-dark brown organic rich topsoil with roots. The unit tends to be a low plastic clayey silt. Distributed throughout this section are non-cohesive sediments ranging in size from fine sand to fine gravel. This interval ranges from 12.5 feet (MW-107D) to 16 feet thick (B-02).

The uppermost sand unit (S-4) generally is described as a loose to medium dense, grayish-brown well-rounded sand. The sand ranges from a very clean, poorly sorted sand to a silty sand. The thickness ranges from 13.5 feet (MW-106D) to 26.5 feet (B-01). Water was not encountered in the S-4 sand unit at any of the new monitoring wells installed as part of the RFI field activities.

The uppermost clay unit (C-3) can be generalized as having a density ranging from soft to stiff, light to dark brown, low to medium plastic silty clay. This unit ranges in thickness from 4.5 feet (B-2) to 16 feet (MW-106D).

The second sand unit encountered (S-3) generally is described as a loose to medium dense, light brown to tan, well-graded sand. This sand unit is bisected by the static

groundwater table. The thickness ranges from 10 feet (MW-102D) to 23 feet (MW-105D).

Clay unit C-2 is described as a soft to stiff, light brown to olive gray, low to medium plastic silty clay. The unit ranges in thickness from 6 feet (MW-5D) to 15 feet (MW-105D). The clay unit (C-2) underlying S-3 was not encountered in any boring or monitoring well borehole drilled as part of the RFI field investigations. However, descriptions of this unit and the thickness of S-3 were obtained from previous well logs developed by others.

The third sand unit encountered (S-2) generally is described as a loose to dense, grey to tannish-brown, fine to coarse grained well-graded sand, occasionally a clayey sand. The thickness of S-2 ranges from 11 feet (MW-105D) to 16 feet (EW-10).

The lowermost clay unit (C-1) is described as a stiff to very stiff, reddish-brown low to medium plastic clay. Non-cohesive sediments distributed throughout this unit include fine sand and calcium carbonate nodules.

The lowermost sand unit (S-1) overlies the Wellington Formation. This sand unit is described as a medium to very dense, reddish-brown, fine to medium-grained, well-graded sand with a trace of silt and clay. The thickness of this unit varied from 7 feet (MW-107D) to 14 feet (MW-106D).

Grain-size and Atterberg Limits

Nine samples were sent to a geotechnical laboratory under chain-of-custody to help determine grain size distribution using ASTM Method D422. Samples were submitted representing the upper three named sedimentary units (S-4, C-3, S-3) from each of the three geotechnical borings (B-1, B-2, B-3). Grain-size distribution curves are presented in Drawings B-1 to B-9, Appendix B.

Sand unit S-4 for all borings was determined to be a fine- to medium-grained well-graded sand as per the ASTM method. Clay unit C-3 could not be determined using this method because of the fine particle size nature of the clay. Sand unit S-3 is a more

uniform sand unit than S-4, and is therefore classified as a fine- to medium-grained, poorly-graded sand.

In addition to grain-size distribution, Atterberg limits (ASTM Method D4318) were performed to determine the relative plastic nature of the cohesive soils (silts and clays). Results of these tests are contained in Appendix B. The three clay units were determined to be medium to highly plastic clays as per the plasticity chart developed by Cassagrande (1948).

Cation Exchange Capacity and pH

Cation exchange capacity (CEC) and pH testing were performed on nine soil samples collected from three soil borings: B-1, B-2, and B-3. From each boring, approximately 2,000 grams of soil were sent under chain-of-custody to a geotechnical soils laboratory from three discrete soil units: S4, C3, and S3. The CEC value is used to assess the ability of the soil to capture positively charged ions. The results are presented in Table 5 and discussed further in Section 5.0.

The clay values ranged from 9.2 milliequivalents per 100 grams (meq/100g) (B-2/C-3) to 16.1 meq/100g (B-1/C-3). This range places the clay in the illite clay mineral group which has a moderate affinity for cations (Drever, 1982). The sands generally ranged from 1.3 meq/100g (B-2/all samples) to 3.0 meq/100g (B-2/S-4). This low CEC value suggests that the sand units have a very low capacity to attract cations. The CEC value for sand unit B-1/S-4 was anomalously high (7.2 meq/100g). This sample appears to contain more clay-type materials than other S-4 samples.

The pH value was necessary to determine the current environment in which CEC is occurring. The relative acidity or base of the environment affects the degree in which contaminants in the groundwater act as cations. The lower the pH (acid), the lesser the effectiveness of the clay to adsorb cations (i.e., lower CEC). The pH range for clay was 7.4 (B-3/C-3) to 8.5 (B-1/C-3). The sand values ranged from 7.2 (B-3/S-4) to 8.7 (B-1/S-4).

Hydraulic Interconnections

The interbedded sands and clays taken together generally act as a single water-supplying aquifer on a regional basis. On a smaller, more local level, some sands are hydraulically cut off from one another by horizontally extensive clay lens beds. For example, well clusters that are known to be screened over discrete units (MW-106, MW-107, and MW-108 well clusters) show a groundwater elevation gradient (approximately 0.2 ft/ft) between the shallow monitoring well screened over sand units S2/S3 (clay unit C2 is absent) and the deep monitoring well screened over sand unit S1. However, data from the continuous water level monitors installed in the shallow and deep wells of the MW-105 cluster indicate that hydraulic communication exists between the S-units. The water levels collected from the continuous water level monitors show that water level fluctuations in the two wells closely mirror each other throughout the year.

Attenuation Capacity

The attenuation capacity of the soils underlying the Facility is a function of several parameters that include the cation exchange capacity, soil pH, and the amount of organic matter present.

The CEC for soil samples taken from the Facility ranged from 1.3 meq/100g up to 16.1 meq/100g, which indicates the cation affinity ranged from very low to moderate. The pH values for the same soil samples ranged from 7.2 to 8.7; thus, the soil environment is essentially neutral and tending toward the alkaline. The soil samples were also analyzed for organic carbon to provide information on the percentage of organic material present that could attract organic compounds. The results of the total organic carbon analysis, Table 5, indicates that only one sample had any detectable organic material, which was reported to be 0.2 percent. These results also indicate the low affinity for organic compounds in the soils on-site.

Degree of Cementation

No cementation of the sedimentary material above the Wellington Formation was noted. An occasional carbonate nodule or gypsum stringer was observed in the sediments.

4.1.1.4 Groundwater Levels

Long-Term Groundwater Level Monitoring

The groundwater levels across the Facility have been continuously monitored using In-Situ Hermit data loggers in four wells since May, 1990 for the purpose of characterizing the local ground water flow. This characterization includes the identification of separate regimes, the direction and magnitude of flow within these regimes, and the influence of temporal changes. The groundwater level data from the four wells, MW-3D, MW-102D and MW-5D and MW-5S are provided in Appendix F.

Using the data generated by the data loggers, monthly and yearly water level graphs have been constructed to show short-term and long-term trends and fluctuations. These graphs representing monthly and yearly trends are contained in Appendix F.

Several observations on the behavior of the individual wells can be made from the water level graphs.

Monitoring well MW-3D, located south of the Facility, is 114 feet in depth. The boring log shows the screen to be 60 feet in length and screened through S3, S2, and S1 sand units. The groundwater levels show small (less than 0.5 foot) daily fluctuations.

Large temporal fluctuations in well MW-3D show overall rises in water level during wet seasons and declines during periods of heavy irrigation and dry season. Two sudden rises in groundwater levels, Appendix F, occurred during the months of April and May of 1991. Both events correspond with high rainfall events noted by WCC field personnel.

Monitor well MW-102D is 127 feet deep and has 14 feet of screen located in the S-1 unit. Long-term monitoring shows daily fluctuations on the order of 0.5- to 1.0-foot. These water level fluctuations may be directly attributed to the pumping of nearby Air Products well No. 15. This water supply well pumps at a rate of approximately 120 gpm on a one-hour on, one-hour off schedule, 24 hours a day. This well is located approximately 1,000 feet west of well cluster MW-102.

Long-term seasonal effects are less dramatic in MW-102D as compared with monitoring well MW-3D. The rainfall events in the Spring of 1991 resulted in more gradual rises in groundwater levels. Also, local summer irrigation resulted in less pronounced temporal groundwater level fluctuations.

Monitor wells MW-105D and MW-105S are 97 feet and 80 feet deep respectively. The deep well has 12.5 feet of screen located in the S-1 unit, while 105-S has 30 feet of screen in the S-2/S-3 unit including the C-2 clay layer. Despite 9 feet of clay separating the S-2 and the S-1 units, the long-term monitoring data in both wells indicate similar groundwater levels or changes. This indicates that the S-3 and S-1 sand units are in direct hydraulic communication.

Potentiometric Surface Maps

Using the groundwater level data collected during the four quarterly sampling events, four potentiometric surface maps have been constructed (Drawings 20 to 23). The contours depicted represent the piezometric surface of the lower sand units (S-1, S-2 and possibly S-3) which represent the aquifer.

The piezometric surface is relatively flat across the Facility, the average gradient ranging between 4.5×10^{-4} to 7.2×10^{-4} ft/ft. These values are below the average regional historic gradient of 1.3×10^{-3} ft/ft (Lane and Miller, 1965). With the addition of monitoring well clusters 106 and 107, additional water level data was collected during the sampling event of June 1991. Figure 23 shows the steepening of the gradient to the east of the Facility. The average gradient increases to 1.9×10^{-3} ft/ft in this area. Subsequent quarterly groundwater sampling events will include collection of water levels from monitoring well cluster MW-108, and will expand our understanding of the groundwater flow patterns at the Facility.

The gradients recorded by Lane and Miller (1965) are similar to those measured recently, but the groundwater levels reported by Lane and Miller are about 15 feet lower than levels recorded at present. This may be a function of local groundwater use and natural fluctuations. Lane and Miller, while studying the natural fluctuations around the Wichita well field north of the Arkansas River, found water level fluctuations occurring from the natural conditions of recharge and discharge through a climatic cycle to be about 8 feet (Lane and Miller, 1965). Data presented by the Kansas Geological Survey suggest that water levels for the area have remained relatively unchanged for the last 30 years (Buddemeier et al, 1991).

There is considerable pumping occurring around the Facility for irrigation, process water, and ongoing groundwater remediation. Drawing 24 shows the wells located within a one and a half-mile radius of the Facility and Table 10 lists the individual well withdrawals. These data were obtained from permit records, well inventory databases, and interviews with farmers and local industries. The Air Products well No. 15 and Abbott extraction wells EW-10 and EW-17 are sufficiently close to the Facility to directly affect the water levels, as indicated by the field measurements. In addition, the abundance of regional high capacity irrigation wells is sufficient to produce a regional lowering of the water table. This lowering however, does not seriously effect the shape of the water level contours directly under the Facility. The direction of flow remains in an east to southeasterly direction.

4.1.1.5 Man-Made Influences Affecting Hydrogeology

Local Water Supply Wells

A total of 68 wells have been identified within one and a half mile radius of the Facility. The main sources of information for well identification include the Kansas Department of Health and Environment and the Kansas Board of Agriculture. Ground water is mainly used for industrial, agricultural, and domestic purposes in the Facility vicinity. Drawing 24 indicates the location of water supply wells and Table 10 provides a summary of information concerning well ownership, ground water use, and other well parameters.

Use of ground water for industrial purposes represents a steady demand for the aquifer. Crop irrigation is more an intermittent activity and water use peaks during the irrigation of cultivated land neighboring the Facility. The effect of irrigation on ground water levels can be observed on the hydrographs generated from data logger information for monitoring wells close to the Facility (see Appendix F).

There are other well categories, such as domestic lawn and garden, oil field water supply, dewatering, and air conditioning. Water demand from these wells is small and usually intermittent. Therefore, their impact on ground water levels is considered minimal.

Two irrigation wells, owned by Mr. Bergkamp, are located between 6,000 and 7,000 feet northwest of the Facility. Air Products owns a small irrigation well. Water from this well is used for lawn irrigation. Thirteen industrial wells were identified within the survey area. These industrial wells are owned by Vulcan Chemicals, Air Products, and Abbott Laboratories.

The two Abbott extraction wells, EW-10 and EW-17, are the closest wells to the Facility, located approximately 500 feet north and 300 feet east-northeast, respectively of the closed pond. Extraction well EW-10 is screened in the S-2 sand unit. Extraction well EW-17 is screened in parts of both the S-2 and S-1 sand units.

Pumping Rates

Well pumping rates can be categorized by well use and operation. Generally, irrigation wells are operated at high rate for short periods of time. Industrial wells are operated at lower rates and continuously throughout the year. Domestic wells are operated at very low rates and periodically. Table 11 presents the average pumping yield of industrial and irrigation wells operated during 1989, which is the latest period for which pumping data were available.

The two major irrigation wells owned by Mr. Bergkamp pumped intermittently at rates of approximately 800 to 900 gallons per minute (gpm) each during the 1989 irrigation season. Air Products owns a small irrigation well which yields approximately 30 gpm

during the summer irrigation season. Abbott extraction wells pump continuously and have yields of approximately 36 and 93 gpm for EW-10 and EW-17, respectively.

Approximate Schedule of Pumping

The actual schedules of pumping for individual wells are not well defined. An approximate pumping schedule can be inferred for wells used for irrigation and industrial purposes, based on information given by well owners to the Kansas Board of Agriculture. The yearly operation of a well is based on 8760 hours per year as submitted to the Kansas Board of Agriculture.

Industrial wells generally pump continuously. Because of this, a percent time of operation close to 100 percent for industrial wells is reported to the Kansas Board of Agriculture. Irrigation wells generally operate only about 10 percent of the time, which represents a small number of pumping hours per year. Well operation time, as determined from the well records, is presented in Table 11.

Man-Made Structures

There are no underground structures at the Facility that could affect the hydrogeology. The closed lagoon leachate collection system and pipes connected to the UIC deep injection well are the only existing pipelines at the Facility. Drawing 6 depicts the existing piping at the Facility.

An NPDES permitted outfall (owned and operated by Air Products and Chemicals, Inc.) discharges into the drainage ditch on the west side of Ridge Road and drains south to Dry Creek (see Drawing 4).

4.1.3 Surface Water Characterization

Surface water within a 1.5 mile radius of the Facility is primarily draws, drainages, and intermittent streams of Dry Creek (south) and Cowskin Creek (north, see Drawing 1). This characterization does not include other NPDES permitted discharges within the 1.5 mile radius. The area is generally flat with areas of rolling plains.

Permanent bodies of surface water within the area include a few stock ponds and the surface impoundments at Vulcan Chemicals to the north. To the southeast, south and west of the Facility are drainages to Dry Creek and Dry Creek itself. Dry Creek is an intermittent stream that flows into Spring Creek to the south. Spring Creek flows into the Ninnescah River, approximately 3 miles southeast of the Facility. An intermittent stream, located northeast of the Facility, drains into Cowskin Creek. Cowskin Creek flows into the Wichita Valley Center Floodway, approximately three miles from the Facility, and then into the Arkansas River. A drainage channel is also located northwest of the Facility. This appears to be a channelization of the upper reaches of Dry Creek.

Drainage patterns from the Facility to the surrounding streams is governed by the relatively flat topography. The railroad line that crosses the area from northeast to southwest (Drawing 4) would likely influence runoff to the west. Surface runoff from the west is diverted to the southwest. Most of the surface runoff within the 1.5 mile radius flows into Dry Creek. A small portion of the runoff drains into Cowskin Creek to the northeast.

The high evapotranspiration rates of the Wichita, Kansas area, estimated to be approximately 42 inches per year (U.S. Department of Commerce, 1990), influence the surface water features. The result is few permanent surface water bodies and many intermittent streams which are dry during most of the year. Permanent bodies of surface water in the area are larger rivers (e.g., Arkansas River) and reservoirs.

A visual observation of the Facility was conducted to assess the presence of sediments which might contain Abbott constituents, according to the procedure in the USEPA-approved RFI Work Plan. No sediments were located during the Facility reconnaissance in the vicinity of the closed pond, the closed drum storage pad, or the closed lagoon. Because no sediments were observed, sediment sampling was not performed at the Facility. Additionally, no sediment samples were collected from the intermittent streams during the RFI field investigation.

4.2.3 Surface Water Investigation

The surface water use survey and characterization indicate that off-site contamination of surface waters and/or sediment with Facility compounds has not occurred. Therefore, further investigation and characterization of this media is unnecessary at this time.

4.2 SOURCE CHARACTERIZATION

This section provides a summary of the source areas in the general format presented in Attachment A of the AOC.

4.2.1 Unit and Disposal Area Characteristics

4.2.1.1 Type and Location

The four SWMUs retained by Abbott are the Evaporation Pond, Evaporation Lagoon, Hazardous Waste Drum Storage Pad, and Underground Injection Control (UIC) Deep Injection Well.

The locations of the SWMUs are shown on Drawing 3. All the SWMUs have been closed under the KDHE direction except the UIC well, which is still in operation. The former solid waste evaporation pond was located between the drum storage pad and the UIC well. The former drum storage pad is located north of the evaporation pond. The former solid waste evaporation lagoon is located in the southwest corner of the Facility. The solid waste UIC deep injection well is located in the southeast corner of the Facility.

4.2.1.2 Design Features

Solid Waste Evaporation Pond. The pond was 150-foot in width by 300-foot in length and 4-foot in depth and was constructed with a compacted clay liner. The evaporation pond was constructed to treat process wastewaters by evaporation with zero discharge. The design capacity was approximately 1.3 million gallons.

Maximum influent flow rate to the evaporation pond was approximately 10 to 15 gpm initially and peaked at an average flow of 28 gpm after several plant expansions. The evaporation pond was closed in 1981 after construction of the evaporation lagoon.

Drum Storage Pad. The drum storage pad was a 70-foot by 65-foot concrete pad with a capacity of 2,184, 55-gallon drums surrounded by an earthen ditch and dike. The pad was used to store waste until the wastes could be recycled or disposed at a permitted disposal facility. All drainage within the pad area lead to a sump and pump collection system.

Solid Waste Evaporation Lagoon. The solid waste evaporation lagoon had a capacity of approximately 8.25 million gallons and was designed to treat wastewater by evaporation with zero discharge. The lagoon was constructed with a clay liner and included a leachate collection system which drained to a sump on the north side of the lagoon. Leachate produced from the leachate collection system originally was pumped from the sump back to the lagoon. After the UIC well was constructed, and at the time of the lagoon's closure in 1987, the collected leachate was disposed down the UIC well. Leachate collected from the lagoon collection system continues to be disposed of by injection in the UIC well.

Solid Waste UIC Deep Injection Well. The well was constructed to dispose of the production wastewater, leachate from the evaporation lagoon, and contaminated groundwater from the ongoing remediation at the Facility. Details of the UIC well installation are shown in Drawing 5. The well is composed of a 7.75-inch diameter outer casing cemented from depth to the surface and a 4.5-inch diameter inner injection string. The annular space between the casing and injection string has historically contained diesel fuel at a surface annular pressure of approximately 150 to 160 psig. Annular pressure monitoring serves as a leak detection method and is required by the UIC well permit granted by KDHE (state primacy).

The well UIC injects into the Arbuckle Formation at depths between 3,978 and 4,646 feet below the ground surface. Wastewater injection is by gravity flow from a surface surge tank. The operating water level in the well is approximately 250 feet below ground surface.

4.2.1.3 Past and Present Operating Practices

The production process used by Abbott involved batch hydrogenation of raw materials in several reaction vessels. The resulting chemical mixtures were then distilled. The higher and lower boiling point fractions were normally by-products and the intermediate fractions were products. The higher and lower boiling point by-product fractions were recycled, burned in the plant's boiler, or shipped off-site for controlled disposal.

Approximately 40 different chemicals were produced over time in the following three product categories:

- Industrial amines;
- Pharmaceutical intermediates; and
- Other industrial chemicals.

An example of an industrial amine is cyclohexylamine, used as an intermediate by others in the production of final products. An example of pharmaceutical intermediate is diethyldipropylmalenate. In summary, the materials produced by Abbott were intermediate materials used by Abbott and by other manufacturers to produce final products.

4.2.1.4 Operating Period

Abbott Laboratories operated at this Site from 1960 to July 31, 1985. Air Products and Chemicals, Inc., bought the operational portion of the Site, but Abbott retained the four SWMUs and the real property on which the SWMUs are located.

The former solid waste evaporation pond was constructed in 1960 and closed in 1981. The drum storage pad was constructed in 1974 and closure of the pad was completed in 1986. The solid waste evaporation lagoon was constructed in 1980 and closed in 1986. The solid waste UIC deep injection well was constructed in 1981 and is still in operation.

4.2.1.5 Unit Age

The age and period of use of the SWMUs can be summarized as follows:

SWMU	Period of Use (Years)	Years of Use
Evaporation Pond	1960 to 1981	21
Evaporation Lagoon	1981 to 1986	5
Drum Storage Pad	1974 to 1986	12
UIC Well	1981 to present	Currently in Use

4.2.1.6 Closure Method

All of the SWMUs have been closed except the UIC well. Only one facility, the drum storage pad was RCRA regulated. Following is a discussion of the closure method for each closed SWMU.

Solid Waste Evaporation Pond. The evaporation pond was closed in 1981. The pond was drained by gravity using a 8-inch PVC irrigation pipe directly into the injection well. Any remaining liquid in the pond was allowed to evaporate prior to closure. Closure was accomplished by pushing in the berm and capping with an 18-inch thick clay cap and a 6-inch thick soil cover followed by an asphalt surface seal to reduce infiltration.

Solid Waste Evaporation Lagoon. The evaporation lagoon closure began in 1986 and was completed in 1987. The evaporation lagoon was originally designed and constructed with a leachate collection system which incorporated a series of perforated pipes laid in aggregate in the bottom of the lagoon. These perforated pipes were manifolded together and connected to a collection sump. During closure, this collection system was connected directly to the UIC well. The evaporation lagoon was emptied of all wastewater and the water was disposed into the UIC well.

Once the lagoon was emptied and its bottom dried, closure began by scarifying the top 8 inches of the bottom soil and recompactting it to 95 percent of its maximum density.

The gunite wall was demolished keeping only the vertical portion of the wall below the capped area to prevent lateral migration of leachate. The top of the concrete walls was broken up and incorporated into the first lift of compacted clay.

Topsoil from the surrounding dikes was stripped and stockpiled for later use. Clay was compacted over the former lagoon in 6-inch layers. Clay from the dikes was supplemented with approximately 13,000 cubic yards of clay from a borrow site. The borrow material had a permeability of 6.03×10^{-9} cm/sec or less.

Clay lifts were placed until the grade was approximately 6 inches below the design grade. The topsoil was graded to a smooth uniform slope and shaped to conform to adjacent contours to provide free drainage without ponding. The topsoil was seeded with a hardy strain grass as specified in the KDHE-approved closure plan.

Abbott's evaporation lagoon closure was conducted in accordance with the KDHE-approved closure documents and a certificate of closure was made by a registered professional engineer.

Drum Storage Pad. Closure of the drum storage pad included power washing of the concrete slab, sampling and analyzing the wash water, sampling and analyzing retained ditch water, sampling affected soils and regrading of the entire site.

Initially, the slab was cleaned with a Delco 3,000 psi, 4.6 gpm hot water system. The slab cleaning was accomplished by dividing the area into four equal segments east-west and washing each segment from south to north. This system of washing controlled the flows to a sampling point in the retaining ditch. Water samples were taken from the ditch and sent to the laboratory for analyses. Samples were tested for ignitability, toluene, and methanol. No positive results were noted. The accumulated wastewater, after testing, was pumped into clean fiberglass tanks and placed into the Abbott UIC deep injection well.

Once the slab washing was completed, nine soil samples were taken around the slab perimeter and tested for specified hazardous criteria, ignitability, toluene, and methanol. The analysis of the soil samples showed no hazardous characteristics as specified by

ignitability, ethanol content, and toluene content (Midwest Analytical Laboratories, 1986). The closure certification and pertinent correspondence regarding the closure of the drum storage pad was previously presented in Appendix C of the Current Conditions Report (WCC, 1990b).

Sample ID	Sample Location	Ignitability	Analyte (ppm)	
			Toluene	Methanol
1	N side NW Corner	Negative	ND(0.01)	ND(0.05)
2	N Side Center	Negative	ND(0.01)	ND(0.05)
3	N Side NE Corner	Negative	ND(0.01)	ND(0.05)
4	E Side N End	Negative	ND(0.01)	ND(0.05)
5	E Side S End	Negative	ND(0.01)	ND(0.05)
6	S Side E End	Negative	ND(0.01)	ND(0.05)
7	S Side W End	Negative	ND(0.01)	ND(0.05)
8	W Side S End	Negative	ND(0.01)	ND(0.05)
9	W Side N End	Negative	ND(0.01)	ND(0.05)

Source: Midwest Analytical Laboratories, 1986.

With all cleaning, sampling, and analysis completed, the existing earthen dike was leveled out. Drainage was directed to existing surface waterways. The topsoil was seeded after the grading was accepted by an Abbott representative.

4.2.1.7 General Physical Condition

The former evaporation pond, evaporation lagoon, and drum storage pad were in continuous operation until their respective closings. At the time of closure, all SWMUs were in good physical condition and performing as designed. The UIC deep injection well is still in operation and continuous monitoring of it suggests that its operation is safe and follows state and federal regulations.

4.2.2 Waste Characteristics

4.2.2.1 Type

The type of waste generated by the operational portion of the Site during the period of Abbott ownership was associated with Abbott's processes. Therefore, waste quantities and type varied with time as the plant expanded.

The various categories of wastes and the environmental control facilities used for each waste category were:

Waste	Environmental Control Facility
Wastewater	Evaporation Pond Evaporation Lagoon Septic tank and drain field UIC well NPDES discharge
Process by-products Used filters and solvents	Drum storage pad

Table 2 is a summary of each of the waste disposal facilities used for environmental control.

The following is a discussion of each of the wastes and waste control facilities.

Wastewater. The sources of process wastewater were:

- Wash down water;
- Process generated water;
- Steam condensate;
- Cooling tower blowdown;
- Water softener regeneration water;

- Sanitary sewer wastewater; and
- Boiler blowdown.

The wastewater system is shown schematically in Drawing 7 for the period prior to 1981, 1981-1986, and after 1986. The volume distribution between the NPDES discharge and the flow to the UIC well is unknown.

All wastewater was collected by the plant sewer and sump system. The wastewater contained trace amounts of raw materials, products, and by-products (KDHE, 1988). Table 3 lists the chemicals found in the wastewater.

Wastewater was discharged to the evaporation pond from plant opening in 1960 until 1981. The majority of the organic loading to the pond was estimated to be ammonia and amines (KDHE, 1988).

Wastewater was discharged to the approximately 5-acre evaporation lagoon beginning in 1981. The design capacity was 8.25 million gallons and it was constructed with a clay liner and leachate collection system. Collected leachate was pumped back into the lagoon for evaporation. Drawing 6 shows the piping for the lagoon leachate collection system, extraction wells, and injection well.

Wastes present in the water discharged to the evaporation lagoon included acetates, ammonia, amines, cyclohexanol, and cyclohexanone. The wastewater was not considered a hazardous waste by USEPA Region VII or KDHE (KDHE, 1988).

Abbott (and later Air Products and Chemicals, Inc.) made process and wastewater system changes to reduce the volume and the organic load to the lagoon. The evaporation lagoon was closed in 1986. Liquid remaining in the lagoon was disposed of by injection into the UIC well.

Wastewater was injected down the UIC well after the evaporation lagoon was closed in 1986. The only exceptions were cooling tower blowdown water and water treatment system regeneration water which were discharged through an NPDES discharge point.

The NPDES discharge could not be used during certain weather conditions. During these conditions, the NPDES wastewater was injected into the UIC well.

The plant's sanitary sewer was discharged to a septic tank and lateral drain field until 1981, when it was rerouted to the evaporation lagoon. When the evaporation lagoon was closed in 1986, sanitary sewer wastewater was discharged to the UIC well.

Drum Storage Pad. Waste process by-products (higher and lower boiling point materials from distillation process) were drummed and stored on the Drum Storage Pad. The drummed by-products were ultimately either reworked in the process, sold, or used as boiler fuel.

Used filters and waste solvents were also drummed and picked up by waste disposal firms. These were also considered RCRA wastes (wastes solvents F003 and F005). The waste solvents were primarily methanol and toluene. Both the drummed filters and waste solvents were stored on the Drum Storage Pad for pick up by the waste disposal firms.

In summary, drummed wastes stored on the Drum Storage Pad were (KDHE, 1988):

Waste	USEPA Hazardous Waste Identification Number
Ignitables from alkylamine distillation	D001
Ignitables from ester alkylation distillation	D001
Corrosives from amine and ester production	D002
Spent methanol solvent	F003
Spent toluene solvent	F005
Spent filter cartridges containing toluene	F005

Injection Well. The UIC deep injection well influent consists of extracted groundwater and leachate from the sump of the closed evaporation lagoon. During the closure of the evaporation lagoon, the UIC well was used to dispose of residual lagoon and sump fluids. The well is infrequently used by Air Products and Chemicals, Inc. as an emergency backup when Air Products UIC injection well is inoperable (KDHE, 1988).

During Air Products' use, groundwater from the Abbott extraction well system continues to flow at normal rates to the UIC well. Air Products flow stream is controlled so the total flow does not exceed the Abbott well capacity.

Quantity. The evaporation pond was in operation from plant opening in 1960 until 1981. Wastewater was discharged at a rate of 10 to 15 gpm from 1960 to 1975 and increased to an average flow of 28 gpm from 1975 to 1980.

The total wastewater flow for the evaporation pond was reported as (KDHE, 1988):

TOTAL WASTEWATER DISPOSAL TO EVAPORATION POND		
Year	Tons	Million Gallons per Year at Specific Gravity of 1.0
1960 to 1975	10,000	2.4
1975 to 1980	20,000	4.8

The organic compounds were only a fraction of the total flow to the waste disposal system. These were primarily ammonia and amines. Estimates for the years 1979 and 1980 are (KDHE, 1988):

ESTIMATED ORGANIC WASTE DISPOSAL TO EVAPORATION POND		
Waste Chemical	Year	Yearly Discharge Amount to Evaporation Pond (Tons/Year)
Total organic loading	1979	150 to 175
Ammonia	1980	55 to 110
Dimethylamine		45 to 50
Monoethylamine		20 to 25
Monomethylamine		<u>1 to 2.5</u>
Total organic loading	1980	121 to 187.5

The evaporation lagoon had a capacity of 8.25 million gallons and was constructed in 1980 and operated until 1986.

The yearly wastewater disposal for the years 1981 through 1984 were reported as (KDHE, 1988):

YEARLY TOTAL WASTEWATER DISPOSAL TO EVAPORATION LAGOON		
Year	Tons	Million Gallons at Specific Gravity of 1.0
1981	54,351	13.0
1982	31,510	7.6
1983	32,476	7.8
1984	39,511	9.5

The UIC deep injection well influent is composed of extracted groundwater and leachate from the sump of the closed evaporation lagoon.

The volume of water injected per year for the period 1981 through 1990 was (KDHE, 1988):

YEARLY TOTAL WASTEWATER DISPOSAL UIC WELL		
Year	Tons/Year	Million Gallons at Specific Gravity of 1.0
1981	92,740	22.2
1982	250,350	60.0
1983	206,350	49.5
1984	292,605	70.1
1985	Data Not Available	
1986	211,380	50.6*
1987	323,390	77.4
1988	310,390	74.3
1989	283,230	67.8
1990	277,700	64.8

*Instrument failure affected readings for part of year in 1986.

Chemical Composition. Waste constituents identified in the evaporation pond at closure consisted of amines, cyclohexylamine, dicyclohexylamine, N,N-dimethylcyclohexylamine, acrylonitrile, benzene, and toluene.

Waste stored at the pad included spent toluene, methanol, solvent wastes, ignitable corrosive wastes, etc. (USEPA, 1990).

Waste constituents identified in the lagoon at the time of closure consisted of amines, cyclohexylamine, dicyclohexylamine, acrylonitrile, benzene, and toluene (KDHE, 1988).

Of the identified waste constituents, amines (including cyclohexylamine, dicyclohexylamine, N,N-dimethyl cyclohexylamine, acrylonitrile), benzene, and toluene have been detected in the groundwater under the Facility.

5.1 QUARTERLY GROUNDWATER SAMPLING

This section will present the analytical results of samples collected as part of the characterization studies performed during the RFI field investigations. Two general areas of analytical results will be emphasized. The first section summarizes results of the quarterly groundwater sampling, which has been on-going since January 1980 with sampling prior to 1980 on a less rigorous basis. The second section summarizes the results of the waste source characterization sampling, which was performed in accordance with the USEPA-approved RFI Work Plan (WCC, 1991b).

5.1.1 Background

Groundwater sampling has been performed at the Facility since shortly after contamination was discovered in 1977. The frequency of sampling generally has been on a quarterly basis since January 1980.

The quarterly groundwater sampling includes 24 existing monitoring wells (MW-1, MW-3D, MW-4D, MW-4S, MW-5D, MW-5S, MW-8D, MW-8S, MW-16D, MW-16S, MW-101D, MW-101I, MW-101S, MW-102D, MW-102S, MW-104, MS-105D, MW-105S, MW-106D, MW-106S, MW-107D, and MW-107S, MW-108D, and MW-108S), two extraction wells (EW-10 and EW-17), and fluid collected from the 5,000-gallon holding tank prior to its disposal in the injection well (injection well). The monitoring well cluster 108 was installed after the third quarter 1991 sampling event. This well cluster will be included in the December 1991 fourth quarter sampling.

Analytical parameters for the historical quarterly groundwater sampling events have expanded through the years and now include:

- Temperature (field analysis);

- Static water level;
- pH (field analysis);
- Specific conductance (field analysis);
- 2,5-dimethylpyrazine;
- 3(N,N-dimethylamino) propyl nitrile;
- Aniline;
- Toluene;
- Benzene;
- Acrylonitrile;
- Cyclohexylamine;
- Dicyclohexylamine;
- N(3 aminopropyl) Cyclohexylamine;
- N,N-dimethylcyclohexylamine;
- N-methyldicyclohexylamine;
- N-methylcyclohexylamine;
- O-toluidine;
- Pentamethyldipropylenetriamine;
- Piperidine;
- Pyridine;
- Chloride;
- Sulfate; and
- Total organic carbon.

A summary of the analytical results is contained in Appendix G.

5.1.2 Methodology

A variety of methods have historically been used to extract the groundwater from the monitoring wells, including submersible pumps, peristaltic pumps, hand bailers, and dedicated bladder pumps. The latter method has been employed in the last three quarterly sampling events of 1991 (March, June, and September).

Groundwater sampling is now performed through the use of dedicated bladder pumps. Some wells, because of their large diameter and, therefore, their large purge volumes contain a two pump system. One pump is used for the rapid purging (at 2 to 3.5 gpm) of water while the other pump (a teflon-lined bladder pump) is used for collecting the water into sample containers. Two wells (MW-101S and MW-102S) have only the sample bladder pump installed because of low recharge rates in these monitoring wells.

5.1.3 Findings

The following observations are based upon the groundwater analysis results that have been collected since January 1980 (Appendix G). The chemicals of concern concentrations have varied both temporally and geographically across the Facility. A summary of the groundwater sampling analytical results for the third quarter of 1991 are presented in Table 12.

Amine Compounds

Generally, concentrations appear to have decreased through time for many analytes in many of the monitoring wells. This observation is best demonstrated by the extraction wells (EW-10 and EW-17) which collect groundwater from a large area. A review of the historical analytical data, going as far back as 1978, indicates the following trends in chemical concentrations:

- The total amine levels have decreased in Wells 10, 16S, and to some extent in 101I. Concentrations in other wells have been non-detect or have remained at relatively constant levels.
- Aniline concentrations in Wells EW-10, EW-17, MW-101I, and MW-101S have dropped to non-detectable levels. Well 16-S, the only other well showing aniline, has a declining trend.
- The concentration of acrylonitrile has dropped to non-detectable levels in all wells except Well MW-101S.
- The hexylamine compounds appear to be the most persistent in regards to both their concentration and incidence of detection.

Tables summarizing the historic analytical data are presented in Appendix G, Groundwater Laboratory Analysis Results.

Amines have historically been concentrated in four areas: monitoring well clusters MW-16 and MW-101, and extraction wells EW-10 and EW-17. In addition, amine detections are approximately one order of magnitude higher in concentration for a given amine constituent in monitoring well cluster MW-101, as compared to the remainder of the monitoring wells.

Volatile Organic Compounds

The detection of volatile organic compounds (VOCs) tends to be concentrated in wells located in the northwest and central portions of the Facility. Samples from monitoring well clusters MW-4, MW-8, MW-16, and MW-101 display elevated concentrations of chlorinated hydrocarbons (tetrachloroethylene, trichloromethane, and tetrachloromethane) in addition to benzene, toluene, ethylbenzene, and xylene (BTEX).

It should be noted that the source characterization, performed as part of the RFI field activities did not detect the presence of VOCs at or beneath the closed pond and lagoon.

Chlorides

Chloride results are presented in Appendix G. Historic results have generally tended to be in the range of 20 to 200 mg/l with occasional readings exceeding 1,000 mg/l. The geometric mean of the general range compares with the published geometric mean concentrations of chlorides (79.2 mg/l) for 50 water wells in Sedgwick County, Kansas (Lane, 1965b).

Sulfates

Sulfate results are presented in Appendix G. The general range of sulfates have been approximately 10 to 100 mg/l with some anomalous readings exceeding 175 mg/l. The geometric mean of the general range compares with a published geometric mean of sulfates (130.7 mg/l) for 50 water wells in Sedgwick County, Kansas (Lane, 1965b).

Total Organic Carbon

Total organic carbon (TOC) results are presented in Appendix G. Results generally ranged from 10 to 100 mg/l for all sample locations with the exception of the MW-101 well cluster. The TOC levels in these three wells tend to be approximately one-order of magnitude greater: 100 to 1,000 mg/l.

5.2 WASTE SOURCE CHARACTERIZATION SAMPLING

The wastes directed to the evaporation pond and the evaporation lagoon came from similar processes. However, a number of factors may combine to account for the differing constituents that were found in the shallow and deep waste source characterization for the pond and lagoon. These factors include:

- Length of use - The pond was in use for over twenty years (1960 to approximately 1981); the lagoon was in use for approximately five years (1981 to 1986).
- Differences in construction - The pond bottom was a single clay layer; the lagoon bottom was engineered to prevent vertical migration of

wastes and consisted of two compacted clay layers with an intermediate leachate collection system.

- Differences in maintenance - The maintenance of the lagoon was more rigorous and regular than the pond maintenance.

The EPA-approved RFI Work Plan was designed to investigate the potential differences in contamination from each unit. Separate sampling was performed for both the pond and lagoon. Those constituents found in the shallow sampling for each unit were investigated in the deep waste source sampling.

5.2.1 Shallow Waste Source Samples

Shallow waste source characterization includes soil samples from the Evaporation Pond. Results of soil analysis from EP-1 and EP-2 are provided in Table 6. The range of detection varied from 5.1 mg/kg of 3(N,N-dimethylamino)Propyl nitrile in EP-2 to 1,400 mg/kg for both cyclohexylamine and N(3-Aminopropyl) Cyclohexylamine in EP-1.

Total organic carbon (TOC) was detected in both EP-1 (13,000 mg/kg) and EP-2 (11,000 mg/kg).

5.2.2 Lagoon Leachate Samples

Results of the lagoon samples are provided in Table 7. Three leachate samples were collected, one field sample (L-1), one field duplicate (L-2), and one field blank (L-3). Only two amine compounds were detected in the leachate samples: N-methylcyclohexylamine (0.8 mg/l, L-1 and 0.44 mg/l, L-2) and N-methyldicyclohexylamine (0.76 mg/l, L-1).

Total organic carbon was detected in both L-1 (40 mg/l) and L-2 (240 mg/l).

In addition, the leachate samples were analyzed for total and dissolved metals. Maximum contaminant levels (MCL) and secondary maximum contaminant levels (SMCL) will be used to compare the level of metals detected in the leachate with those standards established by the USEPA's National Primary and Secondary Drinking Water

Regulations. The following metals were found in the leachate samples which exceeded the MCLs arsenic (6.0 mg/l, L-2), barium (1.6 mg/l, L-1), chromium (0.41 mg/l, L-1), copper (4.0 mg/l, L-2), iron (200 mg/l, L-1), lead (0.25 mg/l, L-2), and nickel (1.0 mg/l, L-1).

No analytes were detected in the field blank (L-3).

5.2.3 Deep Waste Source Samples

Deep waste characterization samples (WS-01 at 20, 34, and 48 ft bgs) were collected underneath the evaporation pond and analyzed for those constituents detected during the shallow waste source soil sampling (see Table 6) in accordance with the EPA-approved Work Plan. Chemical laboratory results indicated a concentration of cyclohexylamine at 530 mg/kg at 34 feet bgs. The rest of the amines were detected at lower concentrations ranging from 10.6 mg/kg for aniline to 450 mg/kg for N-methylcyclohexylamine. Iron was detected at 11,000 mg/kg, the highest metal concentration. Total organic carbon was detected at a concentration of 3,100 mg/kg (Table 6).

Deep waste characterization samples (WS-02 at 20, 33, and 46 ft bgs) were collected underneath the evaporation lagoon and analyzed for those constituents detected during the lagoon leachate sampling (N-methylcyclohexylamine and N-methyldicyclohexylamine), in accordance with the EPA-approved Work Plan. N-Methylcyclohexylamine was detected beneath the lagoon at a concentration of 0.38 mg/kg at a depth of 33 ft bgs. N-methyldichyclohexylamine was not detected in any lagoon deep waste source characterization sample. Iron was detected at 9,000 mg/kg at both 20 and 33 feet bgs. Total organic carbon was detected at a concentration of 330 mg/kg at 20 feet bgs (Table 6).

CONTAMINATION FATE AND TRANSPORT

The previous sections of this report have discussed contaminant source areas and described chemicals associated with past disposal activities at the Facility. The results of chemical analyses of environmental samples have also been presented. The previous studies have identified two major groups of chemicals in soil and groundwater samples from the Facility:

- Amine compounds; and
- Volatile organic compounds.

An essential part of characterizing the potential migration of chemical releases involves understanding the physicochemical properties of the compounds identified at the Facility. The properties of the chemical contaminants combined with environmental fate and transport process are significant factors governing the potential migration of contaminants.

Section 6.1 and 6.2 describe key environmental fate processes and also discuss the physicochemical properties of the most prevalent contaminants identified at the Facility. Because site-specific factors such as geology and hydrogeology are not considered in these two sections, this information alone is insufficient for understanding the potential migration of contaminants at the Abbott site. The information presented is intended to provide general background on those factors that may affect contaminant mobility and predicting potential releases into various environmental media. Section 6.3 integrates the information presented in Sections 6.1 and 6.2 with Facility-specific data which address important migration routes.

6.1 POTENTIAL ENVIRONMENTAL FATE PROCESSES

As stated, the potential for a chemical to be released to the environment and its subsequent environmental fate is partially influenced by several chemical and physical

processes. The key environmental processes affecting contaminant releases are summarized in Table 13. However, other environmental processes affect the degradation or movement of contaminants between various environmental media (i.e., air, water, and soil). The mechanisms are summarized in Table 14.

In addition to environmental processes, various physicochemical and biological processes also serve to influence the mobility and chemical fate of contaminants. These processes specifically relate to interactions between contaminants and environmental matrices (i.e., soils). Table 15 presents a summary of these processes.

Sections 6.1 and 6.2 as well as Tables 13 through 15 present preliminary information while Section 6.3 specifically discusses the potential mobilities and environmental fates of the contaminants identified at the Facility. The objective of Section 6.3 is to establish a relationship between potential contaminant mobility at the sites and the results of soil and groundwater analyses. This relationship is important in defining the Facility-specific potential for off-site contaminant migration.

6.2 GENERAL PHYSICOCHEMICAL PROPERTIES OF AMINES, AND VOLATILE ORGANIC CHEMICALS

This section presents a summary of the physicochemical properties of the three classes of chemicals identified at the site. A discussion of how these properties affect the persistence and potential mobility of each class of chemical is also provided. Specific examples of the amine compounds, and VOCs have been selected to illustrate the general fate and transport characteristics of each chemical class. The chemicals selected in this section represent the more prevalent compounds detected in groundwater at the Facility.

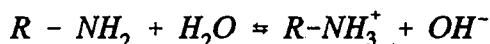
6.2.1 Amines

The results of groundwater analyses, as presented previously, have indicated the presence of various amine compounds known to have been manufactured by Abbott Laboratories. The presence of the amines in the groundwater are related to past on-site waste disposal activities.

Nitrogen, because of its atomic structure, may form three covalent bonds. When three hydrogen atoms participate in covalent bonds with nitrogen, the resulting molecule is ammonia, NH_3 . Derivatives of ammonia form when one or more of the hydrogen atoms are replaced with various organic groups. These derivatives are called amines.

The amines are divided into three major groups (primary, secondary, and tertiary) based on the number of hydrogen atoms replaced by an organic group(s). Drawing 25 presents the general structure of some of the amine compounds detected at the Facility.

Amines, in general, act as a base or proton acceptors according to the equation presented below:



The reason for this basicity is that in ammonia and the amines, there is a pair of unshared electrons not involved in covalent bonding. This electron pair, however, can be phased with a proton or a hydrogen ion. The electron loan pair on the nitrogen atom of the amines make the molecule polar, which explains why amines are soluble in water and act as bases.

Two factors affect the solubility of amines in water: molecular weight and the degree of substitution. The primary amines are generally more soluble in water, followed by secondary, then tertiary amines.

The solubility and the ionic nature of the amine compounds are important factors in evaluating fate and transport of amines related into the environment. Table 16 presents the chemical and physical characteristics of the Abbott constituents. The information presented in Table 16 also indicates that the higher molecular weight amines are less soluble than lower weight amines. The less soluble nature of a given compound reduces that compound's propensity for movement in the aqueous phase. Those organic amines not soluble in water are, however, soluble in alcohol or other organic solvents.

The following section presents the environmental fate and transport of several of the amine contaminants of concern found at the Facility. These amine compounds are presented by structural group; primary, secondary, and tertiary amines. Within these groups, certain compounds are highlighted due to the available information about their chemical/physical characteristics and their environmental fate and transport (shown in Drawing 26). For those compounds with little available information, generalizations are made.

6.2.1.1 Primary Amines

Primary amines consist of an ammonia (NH_3) molecule where one of the hydrogen atoms is replaced by an organic group. The organic group could be a methyl group (CH_3), an aromatic benzene ring, or an even more complex molecule. The primary amines found in a significant number of wells at the Facility include:

- Aniline;
- Cyclohexylamine; and
- O-Toluidine.

The structures for these compounds as well as those secondary and tertiary amines found through the sampling activities are shown in Drawing 26.

All three of these compounds have a six carbon ring structure bound to the nitrogen as the organic molecule. The difference between the three amines is that the cyclohexyl group is aliphatic in nature while the ring attached to aniline and O-toluidine is fully aromatic or has a resonance structure. O-toluidine has an additional methyl group bound to the benzene ring.

The molecular structure influences the solubility of these compounds (see Table 16). All three of these compounds are relatively soluble in water and, therefore, possess a degree of mobility in the aqueous phase. The solubility of these compounds also aid in their availability for biodegradation. Aniline and cyclohexylamine are known to readily degrade in soil, sediments, and water.

The vapor pressure of these compounds indicates that, if they were released onto surface soil or into surface water, cyclohexylamine would be subject to some vaporization, while aniline and O-toluidine would be less volatile. However, exposure to the atmosphere would result in photo oxidation as the result of interaction with ultraviolet radiation, ozone, and with other atmospheric radicals.

Aniline exhibits a low to moderate sorption to soils with the sorption being stronger at lower Ph. Aniline forms covalent bonds with organic material in soil, such as, humic acids and also is sorbed to clay minerals. Cyclohexylamine is not known to be adsorbed to soil materials and the sorption of O-toluidine to soil materials is also not known.

6.2.1.2 Secondary Amines

The secondary amine compounds have two of the three hydrogen atoms replaced by organic molecules. The secondary amines found at the Facility are:

- Piperidine;
- Dicyclohexylamine; and
- N-Methylcyclohexylamine.

The water solubilities of the secondary amines range from miscible for piperidine to slightly soluble for the other two compounds. Thus, in the presence of water, all three compounds exhibit some ability to dissolve in the aqueous phase, to varying degrees, and therefore be mobile. In water, at a neutral pH, piperidine quickly protonates into its ionic form.

Piperidine is known to be biodegradable in soil and water environments. Dicyclohexylamine and N-methyl cyclohexylamine are also expected to biodegrade, but to a lesser degree than piperidine. Adsorption of piperidine to soil particles is not thought to be a significant process and, therefore, piperidine should not be retained in soils. The adsorption characteristics of the other two compounds are assumed to be similar especially because of the readily dissociated nature of these compounds under neutral conditions.

Of the three secondary amine compounds present, piperidine also has the highest vapor pressure and thus, may volatilize. If released to the atmosphere, the degradation of secondary amines would be similar to the primary amines.

6.2.1.3 Tertiary Amines

The tertiary amines, as shown in Drawing 26, represent some of the more complex amine structures found at the Facility. The compounds included as tertiary amines are:

- N-methyldicyclohexylamine;
- N,N-dimethylcyclohexylamine;
- Pentamethyldipropylenetriamine; and
- 3(N,N-dimethylamino)propyl nitrile.

The compounds generally have higher molecular weights than the other amine compounds, which contributes to the overall insolubility of these compounds into water. These compounds are, however, more basic in nature than the primary and secondary amines. Thus, pH strongly influences solubility, ionization, and mobility in the aqueous environment.

As a group, the tertiary amines have relatively low vapor pressure and thus, vaporization, when released to the environment, is correspondingly low.

The adsorption potential of the tertiary amines and their interaction with the soil particles are not widely known and thus the fate of the tertiary amines in soils or groundwater is not known.

6.2.2 Volatile Organic Compounds

The waste source characterization performed as part of the RFI field activities did not indicate the presence of volatile organic chemicals (VOCs) in the pond shallow waste source characterization samples or the lagoon leachate samples. Because of these

analyses, it is concluded that the VOCs that are detected in the groundwater samples collected from the Facility monitoring wells did not originate from the Facility, but migrated from an off-site source.

The VOCs detected in groundwater samples collected at the Facility include two groups, the aromatic and the chlorinated volatile organic compounds. Benzene and toluene are the two aromatic compounds detected in the groundwater samples. The chlorinated VOCs found include tetrachloroethylene, trichloromethane, and tetrachloromethane. The physicochemical properties of this class of compounds are markedly different than those of the amine compounds suggesting the potential for different fate and transport mechanisms.

VOCs exhibit significantly higher vapor pressures than the amines. Therefore, VOCs possess a greater potential for releases to air through volatilization. The VOCs also possess greater solubility in water than the amines. Because of this fact, the VOCs are relatively mobile in soil (depending upon soil type). The magnitudes of the log K_{ow} (octanol/water partition coefficient) values for VOCs indicate that retardation by soils would be moderate.

6.2.2.1 Aromatic Volatile Organic Compounds

Benzene

Benzene is a commonly used industrial solvent derived from the coking of coal and through refining of crude petroleum. Its primary use is in the manufacture of other chemicals.

The chemical/physical properties of benzene greatly influence its environmental fate and transport. Benzene is a soluble (1,791 mg/l in water) aromatic compound and therefore is expected to be mobile if released into groundwater or soil. Benzene is biodegradable in shallow, aerobic groundwater and to a very limited extent under anaerobic groundwater conditions. Rapid degradation requires an acclimated microbial population.

The vapor pressure of benzene is 95 mm Hg at 20°C, which indicate that it would volatilize from surface soil and surface water. Benzene, when released into the atmosphere, is not subject to direct photolysis but does react with photochemically produced radicals.

The octanol/water partition coefficient ($\log K_{ow}$) for benzene is relatively low, 2.13, which indicates that benzene is slightly to moderately adsorbed to soil or sediment. The low $\log K_{ow}$ value and the relatively high water solubility of benzene indicates that benzene is a mobile compound that therefore would be more likely found in groundwater than in soil or sediment.

Toluene

Toluene, also known as methylbenzene, is produced from petroleum, coal, and as a by-product from styrene production. It is used as a solvent and as an intermediate in chemical synthesis.

The environmental fate and transport processes of toluene are similar to those of benzene. When released onto surface soils, toluene will tend to evaporate into the atmosphere where it will be principally degraded by reaction with photochemically reactive hydroxyl radicals. In addition, toluene is moderately adsorbed to soil or sediment, based on its reported $\log K_{ow}$ value (2.69). This property suggests that toluene may be expected to exhibit moderate mobility in soil and, therefore, may leach to the groundwater. Toluene will not hydrolyze under normal environmental conditions. Because toluene's water solubility is less than that of benzene, it is expected to be the slightly less mobile of these two homologous compounds.

Biodegradation of toluene will occur both in soil and groundwater and is dependent upon the presence of acclimated micro-organisms and toluene concentration. A high concentration of toluene is toxic to micro-organisms, thus eliminating any opportunity for biodegradation to occur.

6.2.2.2 Chlorinated Volatile Organic Compounds

The waste source characterization performed as part of the RFI field activities did not indicate the presence of chlorinated hydrocarbons in the pond shallow waste source characterization samples or the lagoon leachate samples. In addition, chlorinated hydrocarbons were not used at the Site when the Site was owned by Abbott. Because of the above, it is concluded that the chlorinated hydrocarbons that are detected in the ground water samples collected from the Facility monitoring wells did not originate from the Facility, but migrated from an off-site source.

Tetrachloroethylene

Tetrachloroethylene (PCE) is an industrial solvent used in dry cleaning operations and as a metal degreaser. Because of its relatively high vapor pressure (4 mm at 20°C), tetrachloroethylene readily volatilizes when released to the surface environment. Once in the atmosphere, tetrachloroethylene may be degraded by reaction with photochemically produced radicals or by ultraviolet radiation. The half-life of tetrachloroethylene in the atmosphere ranges from 1 hour to 2 months.

The water solubility of tetrachloroethylene is 200 mg/l (at 77°F), indicating that PCE is somewhat mobile in the aqueous environment. However, because of its stable chemical nature, PCE in aqueous solutions does not undergo hydrolysis. Based on the observation that peaty soil provides greater adsorption for tetrachloroethylene than sand, it would be apparent that the organic content of a soil influences the adsorption of this compound, and therefore its mobility in soil. Biodegradation occurs generally under anaerobic conditions and, as a process, more significantly than under aerobic conditions. Tetrachloroethylene loss under aerobic conditions is generally through volatilization.

Trichloromethane (Chloroform)

Chloroform is used as an industrial solvent, extractant, and a chemical intermediate. The physicochemical characteristics of chloroform greatly influence its mobility when chloroform is released into the environment. Chloroform has a high vapor pressure

(160 mm at 20°C) and thus, rapidly evaporates when released to the surface environment. Once in the atmosphere, chloroform remains as a vapor and is slowly degraded by reaction with radicals in the atmosphere or by ultraviolet radiation photolysis. The half-life of chloroform in the atmosphere is approximately 80 days.

Chloroform is soluble in water, 5000 mg/l (at 77°F). A release of chloroform to surface water would result in a significant portion volatilizing from the water. However, because of its solubility in water, a significant amount of chloroform should enter the aqueous phase. The biodegradation of chloroform appears to occur primarily with a properly acclimated microbial population and under anaerobic conditions.

Chloroform is adsorbed to soils which are typified by high organic content. It is adsorbed less strongly to clay and not at all to sand. Therefore, the movement of chloroform is expected to be low in high organic soils as compared to low organic soils.

Tetrachloromethane (Carbon Tetrachloride)

Chemical synthesis of fluorocarbons is the most common usage of carbon tetrachloride. Other uses include machinery fire extinguishers or fumigation of stored grain. The fate of carbon tetrachloride is expected to be similar to chloroform. However, carbon tetrachloride is more stable than chloroform because of its structure. In the atmosphere, carbon tetrachloride is very stable, with a residence time of 30 to 50 years. The main degradation mechanism in the atmosphere is photolysis.

Carbon tetrachloride is moderately mobile in soil because of its relatively low affinity for most soil materials. Biodegradation of carbon tetrachloride is limited and generally occurs at a slow rate under anaerobic conditions.

6.3 CONTAMINANT MIGRATION AT THE FACILITY

This section describes the site-specific factors that influence the mobility and potential migration of contaminants from the surrounding subsurface soil into the groundwater.

6.3.1 Fate and Transport in Soil

The physical characteristics of the subsurface at the Facility are described in the sections of this report pertaining to the geology and hydrogeology of the Facility (Sections 2.0, 3.0, and 4.0). Based on information presented in those sections, the following summary is presented:

- The unconsolidated deposits, approximately 100 to 125 feet overlying the bedrock, consist of interlayered sands and clay which have been identified as Tabler silty clay loam and Blanket silt loam.
- The unconsolidated deposits are the major water producing units in central Sedgwick County.
- The vertical permeability of the surficial deposits range from 0.06 to 2.0 inches per hour (4.2×10^{-4} to 1.4×10^{-3} cm/sec) (USDA, 1979).
- The uppermost bedrock unit is the Wellington Formation which is approximately 125 feet bgs and consists mainly of calcareous shale.
- The cation exchange capacity (CEC) for the clay-type soils ranges from 9.2 meq/100 g indicating a moderate affinity for cations. The sand-type soils values for CEC ranges from 1.3 meq/100 g to 7.2 meq/100 g.
- The pH values for the soils ranges from 7.2 to 8.7.

These factors all play an important role in contaminant fate and transport.

The principle mechanism for transport of contaminants in unsaturated soils is infiltration downward to the groundwater table. However, the contaminants found at the site that may be transported by this mechanism are subjected to site-specific factors which may lead to attenuation of contaminant concentrations with depth. These factors, which include clay content, permeability, thickness of the layers of the different soils types, etc., coupled with the physicochemical properties of individual contaminants, govern the fate and transport of contaminants.

6.3.1.1 Fate and Transport of Amine Compounds In Soil

Soil samples that were collected and analyzed as part of the RFI field activities were described in Section 5.2. These soil samples were taken from locations around the closed Evaporation Pond (EP and WS-01) and Evaporation Lagoon (WS-02). The samples were collected to characterize potential waste sources. The samples labeled EP-1 and EP-2 were taken through the asphalt cap covering the former evaporation pond. EP-1 was collected at the western side of the pond to a depth of 9.5 feet. EP-2 was taken from the eastern side of the evaporation pond to a depth of 9.5 feet. The samples analyzed were composited auger cuttings from the entire depth of the hole. The samples labeled WS-01 and WS-02 were collected at depth from underneath the former pond and the former lagoon (Drawings 10 and 11). The samples were collected from a 45° angle at the 20 feet, 33 to 34 feet, and 46 to 48 feet in depth.

The EP samples (as well as the lagoon leachate samples) were analyzed for Abbott constituents as well as the selected Appendix VIII constituents presented in Table 1-2 of the RFI Work Plan (WCC, 1991b). The WS samples (deep source characterization samples) were analyzed for those constituents which were detected in the shallow waste source characterization (the shallow EP samples for the pond and the leachate samples for the lagoon).

Soil samples (B-1, B-2, and B-3) were also taken down to 48.5 feet bgs to characterize the unconsolidated materials above the water table (Drawing 9). The geotechnical results indicate the soil samples to consist of layers of silty sand and clay. The chemical characteristics of the soils indicate pH values ranging from 7.2 and 8.7 and a cation exchange capacity which ranged from 1.3 meq/100 g for the silty sand up to 16.1 meq/100 g for the clay materials. The clay materials had an initial moisture content of 29.5 percent, and the silty sand had 4.5 percent initial moisture content. The total porosity ranged from 34.6 percent in the clay sample to 47.1 percent in the silty sand sample. The percent total organic carbon of the soil samples was also measured. Organic carbon was detected in only one sample. The one sample that had detectable concentrations of organic carbon reported 0.2 percent total organic carbon, and that soil sample was classified as silty sand.

The chemical and physical nature of the soil underlying the Facility greatly influence the mobility or attenuation of the chemicals of concern. The amines, as discussed previously, are generally basic in nature. Thus, in a more acidic environment, the amine compounds will exist in an ionic state. The organic nature of the amines, especially the complex tertiary amines, are attracted to organic material that may be present in soil. The soil underlying the site has a very low organic content as well as a low cation exchange capacity (CEC). The CEC is the ability of a soil to attract cations, or positive charge ions. The low organic content of the soil also decreases the likelihood of the amine compounds being adsorbed to the soil, thus encouraging the mobility of the compounds through the soil medium.

6.3.1.2 Fate and Transport of Volatile Organic Compounds In Soil

The volatile organic compounds (benzene, toluene, tetrachloroethylene, tetrachloromethane, trichloroethylene, and trichloromethane) found in the groundwater beneath the Facility are generally considered to have moderate mobility in soil with regard to transport processes. Potentially, the most chemically active zone for reduction of volatile organic compound concentrations is expected to be at or near the ground surface. This zone is the most active because the principal mechanisms for removal of these compounds from soil are volatilization and biodegradation in the aerobic zone.

Volatile organic compounds also exhibit an affinity for organic material in soil. Therefore, due to the low percentage of organic carbon present in the soil, the volatile organic compounds are not likely to be attenuated by the soil medium, indicating that transport through soil is likely.

The soluble nature of the volatile organic compounds present also influences the transport process. Thus, a major potential pathway for the VOCs migrating downward through the soil is co-percolation with water. Factors which affect the migration of the VOCs are, therefore, the same factors which affect the percolation of water: the permeability of the soil layers, and the chemical interaction between the chemicals of concern and the soil particles.

6.3.2 Fate and Transport in Groundwater

The mechanisms that influence the movement of the chemicals of concern are infiltration of precipitation and the percolation of the infiltrated rainwater down to the groundwater zone. The percolation of water through the soil is dependent upon several factors including the characteristics of the soil material (porosity, permeability, and classification) and the groundwater flow regime. Groundwater flow gradients, hydraulic conductivity, and transmissivity, together with mechanisms of attenuation and dispersion, will affect the movement and concentrations of the chemicals of concern.

The chemical characteristics of the chemicals of concern at the Abbott Facility have previously been discussed. A majority of the compounds, amines, and volatile organic compounds are soluble in water to varying degrees. Those compounds most readily soluble would generally be the most mobile and are those that leave the area of release first. These mobile compounds would then generally be the first to disappear over time. The movement of the remaining compounds would then essentially be related to the solubility. Those more soluble compounds would be carried farther than the slightly soluble compounds. The movement of water through soil occurs initially as a result of gravity pulling the meteoric water down through the larger soil openings while the smaller soil pores take in water as a result capillary forces. The further downward movement ultimately depends upon the geologic characteristics underlying the Facility such as hydraulic gradient, porosity, permeability, and pore size. Movement of water through the subsurface may be accelerated through cracks, fractures, or layers of more porous soils that act as hydraulic conduits.

6.3.2.1 Amines

The subsurface soils present at the Abbott Facility, for the most part, allow for the rapid infiltration of meteoric water in areas that are not paved or capped. The downward percolation results in contact with the waste materials. The chemical characteristics of the water, in particular pH, determine its ability to accumulate the chemical constituents that may be present. The amines, the main constituents of the former Facility's waste, are soluble to varying degrees from very soluble to slightly soluble. The pH of the percolating water as well as the concentration gradient and temperature will also

influence the solubility as a result of the chemical nature of the amine compounds. The amines are slowly moved from the area of deposit into groundwater regime. The distribution throughout the groundwater system, vertical and lateral distribution, is a function of many factors including time, temperature, and the hydrogeological parameters of the area, most importantly hydraulic gradients.

6.3.2.2 Volatile Organic Compounds

The volatile organic compounds found at the Abbott Facility, including both aromatics and chlorinated compounds, have water solubilities that indicate their ability to go readily into solution. The mobility of the compounds, once they are in solution, depends on the hydrogeologic factors. The relative stability of the volatile organic compounds once they are in the groundwater system is the result of the relative reduced environment (where the environment has little oxygen present or air-liquid interface that may encourage volatilization or degradation. Thus, once in the groundwater system the migration of the organic compounds will depend on the geologic, chemical, and hydrogeologic properties of the area.

6.3.3 Fate and Transport in Surface Water

Surface water surrounding the Facility is primarily found in draws, drainage ditches, and intermittent streams north and south of the Facility. Surface water generally is the result of surface runoff. The surrounding topography is relatively flat. High evapotranspiration rates of the area also influences the surface water found around the Facility, and the result is very few surface water bodies.

The transport of the chemicals of concern from the Facility to the few surface water bodies surrounding the site is estimated to be minor. The primary contaminants were discharged as waste to the former ponds and lagoons, and thus were not released to the surface environment. However, if released to the surface, the volatile organic compounds generally have high vapor pressures and volatilize readily, whereas the amines will volatilize to a lesser degree. The chemicals of concern are also characterized by their general biodegradable nature and their mobility as has been previously

discussed. Thus, the transport of the chemicals of concern off-site via surface water is not likely.

6.3.4 Fate and Transport in Air

Airborne contaminants can be derived from two possible sources: namely, volatilization from surface release of the compounds and fugitive dust emissions from surface soil containing absorbed compounds.

The migration of the chemicals of concern to the atmosphere is not a complete pathway because of discontinued operations at the Facility and the proper closure of the potential sources, namely the evaporation pond and lagoon. Any past releases of the chemicals of concern, as a result of the dynamic atmospheric environment, have long since dissipated.

6.4 SUMMARY

The mobility and migration of the chemicals of concern found at the Abbott Facility is governed by a variety of physicochemical, environmental, and site-specific geologic factors. The two general classes of compounds detected in the groundwater at the Facility are amines and volatile organic compounds. The volatile organic chemicals are believed to have originated from an off-site source.

Generally, both classes of compounds exhibit some degree of mobility. The general physicochemical properties, concentration and specific form (i.e., sludge) of the compound also influence mobility. The most influential aspect affecting location of the chemicals of concern within the groundwater system is related to the hydrogeologic factors of the site and the surrounding area.

ANALYTICAL DATA QUALITY

Analytical data packages that contained results for the following samples were reviewed for data quality:

- September 1990 groundwater sampling event;
- December 1990 groundwater sampling event;
- March 1991 groundwater sampling event;
- June 1991 groundwater sampling event;
- April 1991 leachate sampling; and
- Shallow and deep waste source characterization sampling.

Wilson Laboratories produced the September 1990 and December 1990 sampling data packages while Continental Analytical Services, Inc. (CAS) has provided the rest of the data packages. Data packages were evaluated for quality of data using the following:

- Quality control (QC) criteria in specified methods;
- Field QC samples; and
- A project-specific Quality Assurance Project Plan.

7.1 WILSON LABORATORIES DATA PACKAGES

Limited supporting QC data were supplied with the data packages from Wilson Laboratories. The supporting QC data should include preparation and analysis times, limited method blank data, limited matrix spike/matrix spike duplicate data, and reporting of the analytical methods used.

Due to the limited QC data supplied, a limited data review was conducted. Results of the review suggest the low levels of methylene chloride and bis(2-ethyl hexyl)phthalate reported for samples are due to laboratory contamination. These two compounds are considered common laboratory contaminants. However, results for all method blanks for methylene chloride and bis(2-ethyl hexyl)phthalate were not reported; therefore, some or all sample results may reflect actual levels of these two compounds in the samples. Samples for semi-volatiles analyses collected in September 1990 were extracted beyond the 7-day holding time. However, only phthalate esters were detected in the samples. Results for these compounds should be considered estimated values.

7.2 CAS DATA PACKAGES

CAS has provided analytical services for the quarterly groundwater sampling since January 1991. CAS also provided analytical services for the leachate and shallow and deep waste source characterization sampling which were collected as part of the RFI field activities. Supporting QC data were provided by CAS for all of the data packages. The supporting QC documentation consisted of the following:

- Laboratory matrix spike/matrix spike duplicate data;
- Surrogate data; and
- Preparation/analysis dates.

The QC documentation indicated that these data were within defined criteria.

ENVIRONMENTAL STANDARDS

Relevant and applicable environmental standards that pertain to the Facility are as follows:

- NPDES Permit Conditions;
- UIC Injection Well Permit Conditions; and
- U.S. Environmental Protection Agency Drinking Water Standards.

All former solid waste management units except the UIC injection well have been closed. The evaporation pond and lagoon have been closed and capped. The waste drum storage pad was "clean-closed" because there was no evidence of residual contamination. As a result, there are no known sources of air contamination or surface soil contamination. Therefore, environmental regulations applicable to air and surface soils are not applicable. Also, since surface contamination of the Facility is not a concern, regulations involving surface runoff are not applicable to the Facility.

A permitted NPDES discharge is used for plant cooling tower blowdown water and plant water treatment system regeneration water discharge. The plant cooling tower and the plant water treatment system are part of the portion of the Site owned and operated by Air Products and Chemicals, Inc. Although the NPDES discharge is not part of the Facility, the permit conditions are retained as relevant and applicable standards because they relate to liquid waste discharges at the Facility.

Leachate collected from underneath the closed lagoon is discharged into the UIC well. The groundwater collected from the ongoing remediation at the Facility also discharged to the UIC well. Because the UIC well is the current disposal method for leachate and pumped groundwater, permit conditions for this well are applicable and relevant to the Facility.

Groundwater is the contaminated medium of interest at the Facility. Groundwater uses in the area include irrigation wells and potable water. Therefore, the USEPA drinking water regulations are applicable and relevant to the Facility.

Potential historical sources of groundwater contamination at the Facility were plant wastewater discharges to the evaporation pond and lagoon. There have been no known hazardous waste discharges directly to the soil. Therefore, regulations pertaining to the surface and subsurface soils are not relevant to the Facility.

The following discussion presents the relevant and applicable environmental standards for the NPDES Permit, the UIC Deep Injection Well Permit, and USEPA Drinking Water Standards.

NPDES Permit Conditions

The Kansas Department of Health and Environment (KDHE) Water Pollution Regulations (Title 28, Article 16) for NPDES are based on water criteria categories of agricultural use, aquatic life, contact recreation, and domestic water use. The category of agricultural use is applicable to the Facility because the NPDES discharge is to a roadside drainage ditch located south of the Site. This ditch receives intermittent flow and has no aquatic life, contact recreational use, or domestic water use associated with it. Following are the NPDES discharge agricultural use permit conditions for agricultural use:

Parameter	Units	Maximum Allowable Concentration or Value or Allowable Range
pH	Standard	6.5 to 8.5
Arsenic	mg/l	0.1
Boron	mg/l	0.75
Cadmium	mg/l	0.05
Chromium (hexavalent)	mg/l	0.1
Copper	mg/l	0.2
Lead	mg/l	5.0

Parameter	Units	Maximum Allowable Concentration or Value or Allowable Range
Selenium	mg/l	0.2
Silver	mg/l	0.2
Zinc	mg/l	2.0
Ammonia (un-ionized) as NH ₃ -H	mg/l	0.07
Fluoride	mg/l	1.0
Temperature	°F	90

UIC Deep Well Injection Permit Conditions

The UIC well is regulated by the Kansas Underground Injection Control Program (Permit No. KS-01-173-001). Permit restrictions are:

Parameter	Units	Maximum Allowable Concentration or Allowable Range
pH	Standard	2.0 - 12.5
Total Organic Carbon	mg/l	35,000
Total Organic Halogens	mg/l	10
Toluene	mg/l	1,000
Nickel	mg/l	1.3
Benzene	mg/l	0.66
Acrylonitrile	mg/l	4
Chloride	-	No Limit
Temperature	-	No Limit

USEPA Drinking Water Regulations

USEPA National Primary Drinking Water Regulations (40 CFR 141, 142, and 143, and Drinking Water Regulations and Health Advisories, Office of Water, USEPA, April 1991) specify maximum concentration levels (MCLs) for a variety of parameters including inorganic contaminants, organic contaminants, pesticides, PCBs, and microbiological parameters. MCLs for contaminant categories that are applicable to the Abbott Facility are as follows:

Parameter	Maximum Concentration Level (mg/l)
Inorganics	
Arsenic	0.05
Barium	2.0
Cadmium	0.005
Chromium	0.1
Copper	1.3
Lead	0.005
Mercury	0.002
Nickel	0.1
Nitrate as N	10.0
Nitrite as N	1.0
Selenium	0.05
Organics	
Benzene	0.005
Carbon Tetrachloride	0.005
Chloroform	0.1
Dichloromethane	0.005
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
1,2-Transdichloroethylene	0.1
Ethylbenzene	0.7
Toluene	1.0
Tetrachloroethylene	0.005
Trichloroethylene	0.005
Xylenes (total)	10

BASELINE RISK ASSESSMENT

A baseline risk assessment (RA) was performed to evaluate the potential risks to human health posed by groundwater contamination at the Facility. The term baseline refers to the fact that the evaluation of risks is made for the Facility as it currently exists (i.e., before the completion of any future remedial activities). The results of the RA were used in evaluating potential remedial alternatives for the Facility, including the no-action scenario. The RA is presented as Appendix H of this report.

An ecological assessment was also performed as part of the RA. This assessment consisted of a literature survey of the area ecology, and identification of all threatened or endangered species and potential environmental receptors which could be impacted by Facility chemicals.

Two major groups of compounds were identified in groundwater during the RFI. Chemicals consisted of one group of compounds which were associated with Abbott activities (a number of amine compounds), and a second group of compounds which originated from off-site sources (chlorinated volatile organic compounds). The majority of the Abbott compounds are non-carcinogenic and are relatively non-toxic. In contrast, most of the chlorinated volatile organic compounds are either known or suspected carcinogens.

An analysis of potential human exposure pathways at the Facility indicated that groundwater is the only medium with potential for human exposures. Persons entering the Facility or living near the Facility could be exposed to chemicals via ingestion of contaminated groundwater. The RA evaluated potential exposures and health risks for two groups of individuals who might ingest contaminated groundwater, on-site industrial workers and near off-site residents. These scenarios represent the range of activities and receptors that may likely come into contact with contaminated groundwater under current land use conditions, although it should be noted that both of these scenarios are hypothetical and unlikely to occur in the foreseeable future.

The RA focused on two separate groups of compounds. Those associated with past industrial activities at the Facility, and those which migrated to the Facility from off-site sources. Groundwater chemicals were identified using on-site and off-site monitoring well data collected in 1990 (four quarters) and 1991 (first two quarters). Exposure point concentrations were developed using data from the most current sampling event (3rd quarter, 1991).

Characterization of potential cancer risks posed by hypothetical exposure to on-site groundwater produced risk estimates in the range of 4.9×10^{-4} (non-Abbott compounds) to 3.6×10^{-6} (Abbott compounds). The potential cancer risks associated with the non-Abbott compounds on-Facility are above the advisory range of 10^{-6} to 10^{-4} established by USEPA. Cancer risks associated with off-site groundwater were substantially lower, ranging from 2.8×10^{-5} (non-Abbott compounds) to 0 (Abbott compounds).

The results of the RA indicate that on-site groundwater could pose a significant health risk to exposed individuals. However, an analysis of the influence of Abbott versus non-Abbott compounds on the cumulative cancer risks and non-carcinogenic health hazards indicates that the non-Abbott compounds contribute the majority of Facility cancer risks and health hazards.

While the potential for Facility-related health risks have been found to exist, it is unlikely that any populations are currently at risk, based on the following:

- There are no receptor populations currently using Facility groundwater for drinking water purposes;
- Ongoing remediation appears to be reducing chemical levels in off-Facility wells. No Abbott compounds were found in any off-site monitoring wells during the most recent sampling event (third quarter, 1991), suggesting that off-site groundwater may now be clean (Abbott compounds only).

NATURE AND EXTENT OF CONTAMINATION

10.1 SUMMARY

Groundwater contamination was discovered beneath the Facility in 1977 and first studied in detail in 1979. Abbott implemented a voluntary remediation program to extract contaminated groundwater and dispose of it in the UIC well. Groundwater monitoring wells were also installed to delineate the contamination. At the time of the initial monitoring well construction, well locations were limited due to property access restrictions.

According to the RFA report (KDHE, 1988), during the years of Abbott's operation of the Site, 1960 to 1985, the only recorded release was a small leak from some drummed wastes on the Drum Storage Pad. This small leak was properly cleaned up. The former evaporation lagoon had a leachate collection system and monitoring wells for release detection, but no releases were recorded. There were no recorded surface releases from the evaporation pond. The UIC well is inspected regularly and there is no record of releases.

Quarterly groundwater sampling was initiated in 1980. Appendix G presents a summary of the sampling results for the individual monitoring wells.

10.1.1 Ongoing Remediation

Voluntary groundwater remediation has been ongoing since 1979. Data from the quarterly groundwater sampling suggest that the current remediation program has been successful in containing and reducing the concentrations of Abbott constituents. An assessment of the current status of this groundwater remediation system is presented in the following sections.

10.1.1.1 Groundwater Extraction System

Abbott continues to control the groundwater beneath the Facility by pumping two extraction wells, EW-10 and EW-17, at rates of 36 and 93 gpm, respectively. These wells formerly were used by Abbott for plant production and potable water purposes. Groundwater extracted from EW-10 and EW-17 is hard-piped to a 5,000 gallon holding tank/equalization tank with gravity flow to the UIC injection well.

10.1.1.2 Quarterly Groundwater Sampling

Groundwater sampling has been performed at the Facility since shortly after contamination was discovered in 1977. Regular quarterly groundwater sampling has occurred at the Facility since 1980.

The quarterly groundwater sampling includes 24 existing monitoring wells (MW-1, MW-3D, MW-4S, MW-4D, MW-5S, MW-5D, MW-8S, MW-8D, MW-16S, MW-16D, MW-101S, MW-101I, MW-101D, MW-102S, MW-102D, MW-104, MW-105S, MW-105D, MW-106S, MW-106D, MW-107S, MW-107D, MW-108S, and MW-108D), two extraction wells (EW-10 and EW-17), and the fluid exiting the holding tank on its way to the UIC deep injection well.

Analytical parameters for historical quarterly sampling have expanded through the years and now include:

- Temperature;
- Static water level;
- pH (field analysis);
- Specific Conductance (field analysis);
- 2,5-dimethylpyrazine;
- 3(N,N-dimethylamino) propyl nitrile;
- Aniline;

- Cyclohexylamine
- Dicyclohexylamine
- N(3 aminopropyl) Cyclohexylamine;
- N,N-dimethylcyclohexylamine;
- N-methyldicyclohexylamine;
- N-methylcyclohexylamine;
- O-toluidine;
- Pentamethyldipropylenetriamine;
- Piperidine;
- Pyridine;
- Chloride;
- Sulfate;
- Total Organic Carbon (sparged);
- Acrylonitrile;
- A number of GC/MS low level volatile organic chemicals; and
- A number of GC/MS extractables.

A summary of the third quarter groundwater analysis is contained in Appendix G. Appendix G also contains tables which present the results of groundwater analysis on well-by-well basis over time.

10.2 GROUNDWATER FLOW

10.2.1 Velocity and Direction of Groundwater

The velocity of groundwater is estimated from groundwater level records taken during each quarterly sampling event. The general direction of the flow, east-southeast, is affected underneath the Facility in localized areas that fall within the cone of depression caused by groundwater extraction wells EW-10 and EW-17. Drawings 20 to 23 depict the potentiometric surface maps developed with groundwater level data from quarterly sampling events.

An approximation of the groundwater velocity can be made by using Darcy's equation:

$$v_d = Ki$$

Where v_d is the Darcy velocity (or specific discharge), K is the hydraulic conductivity and i is the hydraulic gradient. The K value is an average value ascribed to the aquifer derived from aquifer pumping tests (110 ft/day). The observed or measured hydraulic gradient, i , obtained from the potentiometric maps, averages approximately 3.0×10^{-4} ft/ft. Therefore, the calculated Darcy velocity is 3.3×10^{-2} ft/day. Darcy velocity is a macroscopic concept. It refers to the average velocity of water across a cross-sectional area of porous medium (Freese and Cherry, 1979).

While specific discharge has units of velocity, it does not define the average travel time of water between two points. Because the grains of the media occupy much of the volume in the saturated zone, water flows only in the interconnected pore spaces of a medium. The fraction of the total volume of soil media available for the flow of water is called the effective porosity, n_e . The effective porosity is generally smaller than the

total porosity (the volume of voids/total volume) of a medium because some of the voids are not interconnected. To calculate the average velocity of water, the following expression can be used:

$$v_e = \frac{v_d}{n_e}$$

Where v_e is known as the mean effective or seepage velocity.

The total porosity for a sample collected from the S4 sand unit was measured to be 47 percent. For purposes of determining the seepage velocity of the groundwater beneath the Facility, the effective porosity of the unconsolidated deposits beneath the Facility is estimated to range from 0.1 to 0.3 for the sand units. This range is typical for sand (Driscoll, 1986).

The range of seepage velocities can be calculated using the Darcy velocity obtained from the average observed hydraulic gradient at the Facility and the range of effective porosities which are typical for sands. This range of seepage velocities is computed to be 0.1 ft/day to 0.3 ft/day.

This calculated seepage velocity is for the groundwater only and does not necessarily represent the velocity of chemical compounds in the groundwater. Velocities of chemical compounds in the groundwater are affected by chemical mechanisms such as hydrolysis, oxidation, reduction, volatilization, adsorption and biodegradation.

The local direction of the flow is affected by the continuous pumping of extraction wells EW-10 and EW-17. Extraction well EW-10 is screened in the sand unit S2 and EW-17 in sand units S1 and S2. The average pumping rates of each well have been 93 and 36 gallons per minute (gpm) for EW-17 and EW-10 respectively for the years 1989 and 1990. Since 1986, these two wells have been scheduled to operate continuously throughout the year, except for routine maintenance.

It appears that the extraction system has contained the contaminant plume, based on observation of chemical concentration data obtained from the quarterly sampling of

June 1991 (which included well clusters 106 and 107), depicted in Drawings 27 and 28, which show that the chemicals of concern are not detected outside the capture zone of the groundwater extraction system. Additional evidence for this conclusion is provided by the results of the groundwater sampling from monitoring well cluster 108. This well cluster is located southeast of the closed pond, on property to which, until recently, access had been restricted. Chemicals of concern were not detected in the groundwater samples collected from well cluster 108.

10.2.2 Groundwater Chemical Constituents

The results of this RFI have identified two major groups of chemicals in groundwater samples collected at the Facility.

- Amine compounds which were found in the source characterization activities; and
- Volatile organic compounds, which were not found in the source characterization activities.

The presence of amines in the groundwater is related to past on-site waste disposal activities. The amine compounds are divided into three major groups based on the number of hydrogens replaced on the ammonia with organic or carbon compounds. These groups are primary, secondary, and tertiary amines.

The presence of volatile organic compounds in groundwater beneath the Facility is related to off-site sources. Source characterizations performed according to practices outlined in the USEPA-approved RFI Work Plan did not detect the presence of VOCs in the closed pond or closed lagoon.

10.2.3 Physicochemical Properties

The physical and chemical characteristics of the chemical compounds will determine their mobility within the groundwater flow.

Primary amines have specific gravities lower and similar to water. They are soluble in water and biodegradable which increases their mobility.

Secondary amines are also lighter than water and their solubility ranges from miscible to slightly soluble which make them mobile. They are also biodegradable.

Tertiary amines are lighter than water and, overall, insoluble in it. These compounds are basic in nature. The groundwater pH will influence their solubility, ionization, and mobility in the aqueous environment. Tertiary amines are also generally biodegradable.

The aromatic VOCs, benzene and toluene, are lighter than water and are soluble in it, which makes them mobile. Both compounds are biodegradable under limited conditions.

Chlorinated VOCs, tetrachloroethylene, trichloromethane, and tetrachloromethane, are heavier than water and very soluble in it. Biodegradation occurs generally under limited conditions.

10.2.4 Plume Extent

Delineation of the horizontal and vertical plume extent can be achieved using chemical laboratory results from groundwater sampling. Chemical concentration data obtained from the quarterly sampling of June 1991 has been used to delineate the current plume extent.

Horizontally, the plume boundaries outline a trapezoidal area within and around monitoring well clusters MW-4D, MW-4S, MW-16D, MW-16S, EW-10 and EW-17, MW-101S, MW-101I, and MW-101D. Drawings 27 and 28 depict the spatial distribution of selected compound concentrations, of amines and volatile organic compounds, respectively. Vertically, the boundaries of the plume are controlled by the geologic medium. The Wellington formation, which exhibits permeability values in the range of 1.3×10^{-6} cm/sec to 8.6×10^{-4} cm/sec, is considered relatively impervious for any migration of chemicals into the formation. In addition, the 3 foot piezometric head difference between the Wellington Formation and the overlying unconsolidated

formation creates an upward gradient that precludes the migration of chemicals into the formation. This head difference has been observed by others (Buddemeier et al, 1991) and is presented as a partial explanation for the lack of regional water level declines in this area.

The horizontal extent of the plume is controlled by the natural and artificial groundwater flow movement underneath the Facility. The voluntary Abbott extraction system, in operation since 1979, has been pumping the lower sand units, S1 and S2, continuously during these years. The groundwater extraction system controls the horizontal extent of the plume. Amines that were detected in both sand units underneath the former evaporation pond are also detected at the extraction wells, but not at the monitoring wells located downgradient from the extraction wells.

Amines compounds, such as N-methylcyclohexylamine, N, N-dimethylcyclohexylamine, N-methyldicyclohexylamine, and dicyclohexylamine were detected in groundwater from all three wells in the 101 cluster. Concentrations in MW-101S were generally higher than concentrations in the other two wells, but all were within the same order of magnitude. These amine compounds were also detected at the extraction wells, but at lower concentrations.

Chlorinated hydrocarbons such as tetrachloroethylene and trichloromethane were detected at MW-16D, MW-16S, MW-4D, and MW-4S and also at the extraction wells at similar concentrations. Volatile organic compounds were not detected in the source characterization program. The presence of VOCs in the groundwater is attributed to an off-site source.

10.2.5 Velocity and Direction of Plume

Current evidence indicates that the contaminant plume beneath the Facility is being contained by the extraction system. Field data and analytical computations indicate that the existing extraction program, consisting of two extraction wells, EW-10 and EW-17, induce sufficient hydraulic control to prevent migration of Abbott contaminants beyond the capture zone of the wells. Analytical data from groundwater samples collected from the well clusters 105, 106, 107, and 108 all indicate plume capture. Computations using

analytic methods, such as Theis (1935) and Keely and Tsang (1983), also indicate that pumping at the present rates (currently approximately 36 gpm for EW-10 and approximately 93 gpm for EW-17) is sufficient to maintain capture.

Because of the continuously pumping extraction system, the direction of the plume movement beneath the Facility is toward the extraction wells. Average Facility-wide seepage velocity, based upon observed hydraulic gradients and ranges of effective porosity and hydraulic conductivities, was estimated to range from 0.1 to 0.3 ft/day. Velocities will increase near the extraction wells, as increased drawdown creates a steeper hydraulic gradient.

A review of the literature and the chemical properties of the constituents of concern suggest that the amines are generally mobile in water. Because of this, groundwater flow (advection) toward the extraction wells will be the dominant transport mechanism.

10.3 UNSATURATED SOILS

The following sections discuss the presence of constituents of concern in the unconsolidated sediments above the water with respect to their impact as a source of contamination to groundwater.

10.3.1 Soil Sample Type and Locations

Subsurface soil samples have been taken at the Facility according to the USEPA-approved RFI Work Plan. The most recent soil samples collected and analyzed were described in Section 5.2. These soil samples were taken from locations around the closed Evaporation Pond and Evaporation Lagoon. These samples were collected to characterize potential waste sources.

10.3.2 Soil Chemical Compounds

Shallow soil samples were collected at the closed pond, analyzed for selected Appendix VIII constituents as presented in the USEPA-approved Work Plan. All constituents which were detected in the shallow soil samples from the Appendix VIII analysis are

presented in Table 6. Chemical compounds detected in the evaporation pond, at EP-1 and EP-2, were exclusively amines and some metals. Cyclohexylamine and N(3-aminopropyl)cyclohexylamine were detected at concentrations of 1,400 mg/kg each from the sample taken at EP-1 between 9.0 and 9.5 feet bgs. Other amines were detected at lower concentrations ranging from 13.9 mg/kg for 3(N,N-dimethylamino)propyl nitrile to 1,000 mg/kg for N-methylcyclohexylamine at the same location and depth. Iron, detected at 16,000 mg/kg, was the highest concentration among the metals analyzed in the sample taken at EP-1. Total organic carbon was reported at 13,000 mg/kg.

Deep waste characterization samples (WS-01 at 20, 34, and 48 feet bgs) were collected from underneath the evaporation pond. Chemical laboratory results indicated a concentration of cyclohexylamine at 530 mg/kg at 34 feet bgs (Table 6). The rest of the amines were found at lower concentrations ranging from 10.6 mg/kg for aniline to 450 mg/kg for N-methylcyclohexylamine. Iron was detected at 11,000 mg/kg at location WS-01 at 34 feet bgs. Total organic carbon was detected at a concentration of 3,100 mg/kg (Table 6).

Deep waste characterization samples (WS-02 at 20, 33, and 46 ft bgs) were collected underneath the evaporation lagoon. Chemical analyses indicated that N-methylcyclohexylamine was the only amine constituent detected in the deep waste source characterization beneath the lagoon (in WS-02-33). At 0.38 mg/kg, N-methylcyclohexylamine was detected at a concentration just slightly above its detection limit of 0.25 mg/kg. Iron was detected at 9,000 mg/kg at both 20 and 33 feet bgs. Total organic carbon was detected at a concentration of 330 mg/kg at 20 feet bgs.

10.3.3 Transport Mechanism

The principle mechanism for transport of chemical compounds from unsaturated soils into the groundwater is infiltration. However, the compounds found at the Facility which may be transported by infiltration are subjected to Facility-specific factors that may lead to attenuation of the compound concentration with depth. These factors include clay content, permeability, soil layer thickness and soil types combined with the physicochemical properties of individual compounds.

Infiltration of precipitation from the closed pond into the groundwater has been minimized by the pond closure method (consisting of compacted clay fill) and the later construction of an asphalt cap over the pond area. Infiltration from the closed lagoon has been minimized by the continuous operation of the lagoon leachate collection system and sump. Because of this, the impact to groundwater from amine constituents in the unsaturated, unconsolidated sediments beneath the pond and lagoon is anticipated to be minimal or non-existent.

10.4 SURFACE WATER

A reconnaissance of the surface water features on and near the Facility was performed in accordance with the USEPA-approved RFI Work Plan. The results of the reconnaissance indicated that surface water sampling was not required. There are no major surface water bodies that can accumulate water for extended time periods. As indicated in Drawing 4, an area directly south of the closed and capped evaporation pond is low lying with poor drainage. This area does accumulate water following heavy rainfall events. Based on field observations, the accumulated water generally disappears in a few days. The water is removed from this area by evaporation, infiltration, or a combination of both processes.

CONCLUSIONS

11.1 CONCLUSIONS

The following conclusions have been developed on the basis of the observations made and data collected during the RFI activities performed at the Facility:

- The RFI activities have filled the data gaps identified in the RFI Work Plan and have provided sufficient information to satisfy the requirements of the Administrative Order on Consent.
- The source of the amine ground water contamination was the evaporation pond. The contamination occurred during the pond's operational period. The pond is now closed and capped with asphalt and is no longer a source.
- Leachate sampling and deep waste source characterization beneath the closed lagoon indicate that the lagoon is not a significant contributor to ground water contamination beneath the Facility.
- Chlorinated hydrocarbons found in the ground water beneath the Facility is attributed to an off-site source. Shallow source characterization, leachate sampling, and deep waste source characterization did not indicate the presence of non-amine contamination beneath the closed pond and closed lagoon.
- The data collected during the RFI indicate that the ground water contamination is being captured by the existing extraction system. The existing extraction system has been in continuous operation on a voluntary basis since 1979. Additional well clusters constructed as part of the RFI field activities (clusters 106, 107, and 108) were located down gradient from the closed pond and extraction system wells. No ground water contamination of any type was detected at these well cluster locations.
- The current extraction system pumping rate is sufficient to produce a capture zone which captures the amine contaminant plume. Water level data and analytical methods using RFI-derived input data indicate capture of the plume.

- The historical and RFI-derived ground water analytical data suggest that the extraction program has been effective in reducing the levels of many contaminants of concern at the Facility.
- There is no evidence that the ground water quality in the Wellington Shale has been impacted by past Facility activities. The water level data collected during the packer test indicate that a upward vertical gradient exists between the Wellington Shale and the overlying unconsolidated deposits. This would further impede migration of ground water contamination into the bedrock.
- There is no evidence of impact to the surface water on or near the Facility related to the contaminants of concern at the Facility. The visual reconnaissance of surface water features near the Facility indicate that surface water has not been impacted by activities at the Facility.
- There is no evidence of impact to the environment or ecology related to the contaminants of concern at the Facility. The visual reconnaissance and ecological assessment of the Facility indicate that the environment or ecology have not been impacted by activities at the Facility.
- The above conclusions are consistent with the prior understanding of Facility history and the hydrogeological system in the vicinity of the Facility.

11.2 DATA LIMITATIONS AND RECOMMENDATION FOR FURTHER WORK

The RFI activities conducted at the Facility were performed in accordance with the USEPA-approved project documents, dated March 1, 1991 (WCC, 1991b). As with any large data gathering activity, data limitations are inherent in the data gathering process. However, a review of the data collected to date indicates that data quantity and quality are sufficient for the Investigation. Ground water data are available for the Facility as far back as 1978. Therefore, no additional data are required at this time to complete the Risk Assessment or the Corrective Measures Study.

11.3 CORRECTIVE MEASURES ALTERNATIVES

A preliminary screening of potential corrective measures was conducted during the preparation of the RFI Work Plans. The Pre-Investigation Evaluation Report (PER) outlined several corrective measures alternatives for ground water, including (WCC, 1990c):

- Continuation of ongoing interim measures (which include the current extraction system, with disposal of the ground water into the injection well;
- Institutional controls;
- Additional hydraulic control of ground water movement;
- Containment systems;
- Passive recovery systems (such as interceptor drains); and
- Active recovery and treatment systems.

The PER concluded that the long-term corrective action at the Facility is expected to be continuation of the currently operating extraction and injection well system. The PER also concluded that, if treatment of contaminated ground water is warranted, activated carbon, chemical oxidation, or biological treatment are the primary potential treatment technologies for the Abbott constituents.

The evaluation of corrective measures and treatment technologies will be further developed in the Corrective Measures Study Report.